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Geology of the East Fork Mine and Vicinity, Sevier County, Tennessee

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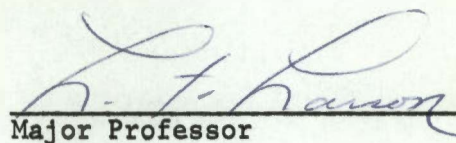
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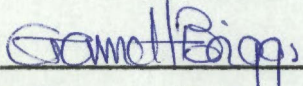
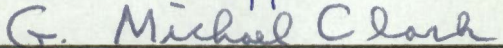
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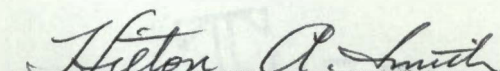
I am submitting herewith a thesis written by John Charles Brower entitled "Geology of the East Fork Mine and Vicinity, Sevier County, Tennessee." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geology.


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and recommend its acceptance:

Accepted for the Council:


Vice Chancellor for
Graduate Studies and Research

**GEOLOGY OF THE EAST FORK MINE AND
VICINITY, SEVIER COUNTY, TENNESSEE**

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

John Charles Brower

June 1973

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ABSTRACT

The East Fork mine consists of a series of open cuts in steeply dipping low-grade metasediments of the Late Precambrian(?) Ocoee Series. In general the metasedimentary units strike northeast and dip steeply to the southeast. However, interpretation of stratigraphy and structure is complicated by intensive local folding and faulting. Two large thrust faults occur in the southern part of the study area, and two or more thrust sheets comprise the bulk of Dixon Mountain in the eastern part of the study area. At the southern boundary of the study area, the Dunn Creek fault thrusts rocks of the Snowbird Group onto those of the Walden Creek Group. Nearby a smaller fault thrusts a sheet of conglomerate of the Shields(?) Formation onto younger slates.

Pods of manganese oxide ore occur in the Walden Creek Group at the top of a laterally persistent dolostone bed. This bed elsewhere caps a sequence of limestone conglomerates that interfinger with lenses of sandy shale. Bedded phosphorite crops out approximately 400 feet northeast of the easternmost manganese mine and occurs in a slightly higher stratigraphic horizon. Earlier studies suggest that the manganese was leached from dolostone by underground water and redeposited as a manganese carbonate ore. "Present field and analytical work indicate that the manganese ore formed as lenses and pods in dolostone. Structure and texture of the ore indicate subsequent fracturing, shearing, and local remobilization.

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CHAPTER I

INTRODUCTION

Thesis Area Location

The 4.7-square mile area described in this thesis is approximately 12 miles east of the town of Sevierville, Tennessee, and is entirely within Sevier County (Figure 1). The study area is roughly three miles long in a northeasterly direction one mile wide at the southwestern end, and two miles wide at the northeastern end (Plate 1, map pocket). The boundaries are determined by easily-located topographic features that encompass an area large enough to satisfy the purpose and scope of this investigation, as explained below. The northern boundary of the study area is formed in part by a stream named Long Branch and in part by the crest of Bearwallow Mountain. The southern boundary is a line extended along the courses of Mill Branch, Mize Branch, and Dunn Creek. The eastern boundary cuts across Dixon Mountain approximately along a lithologic change. The western boundary is approximated by the crests of some small ridges. This area covers part of the Jones Cove and Richardson Cove quadrangles (Plate 1). The term "East Fork" as used in this report refers to the East Fork mine, not to the hamlet named East Fork on the Richardson Cove map. Map locations of features are stated in Tennessee Rectangular Coordinates, abbreviated as "TRC" hereafter. Consistent with the recommendations of the American Geological Institute (Gary, 1972, p. 582), the term "metaquartzite" as distinct from "orthoquartzite" is employed in this thesis.

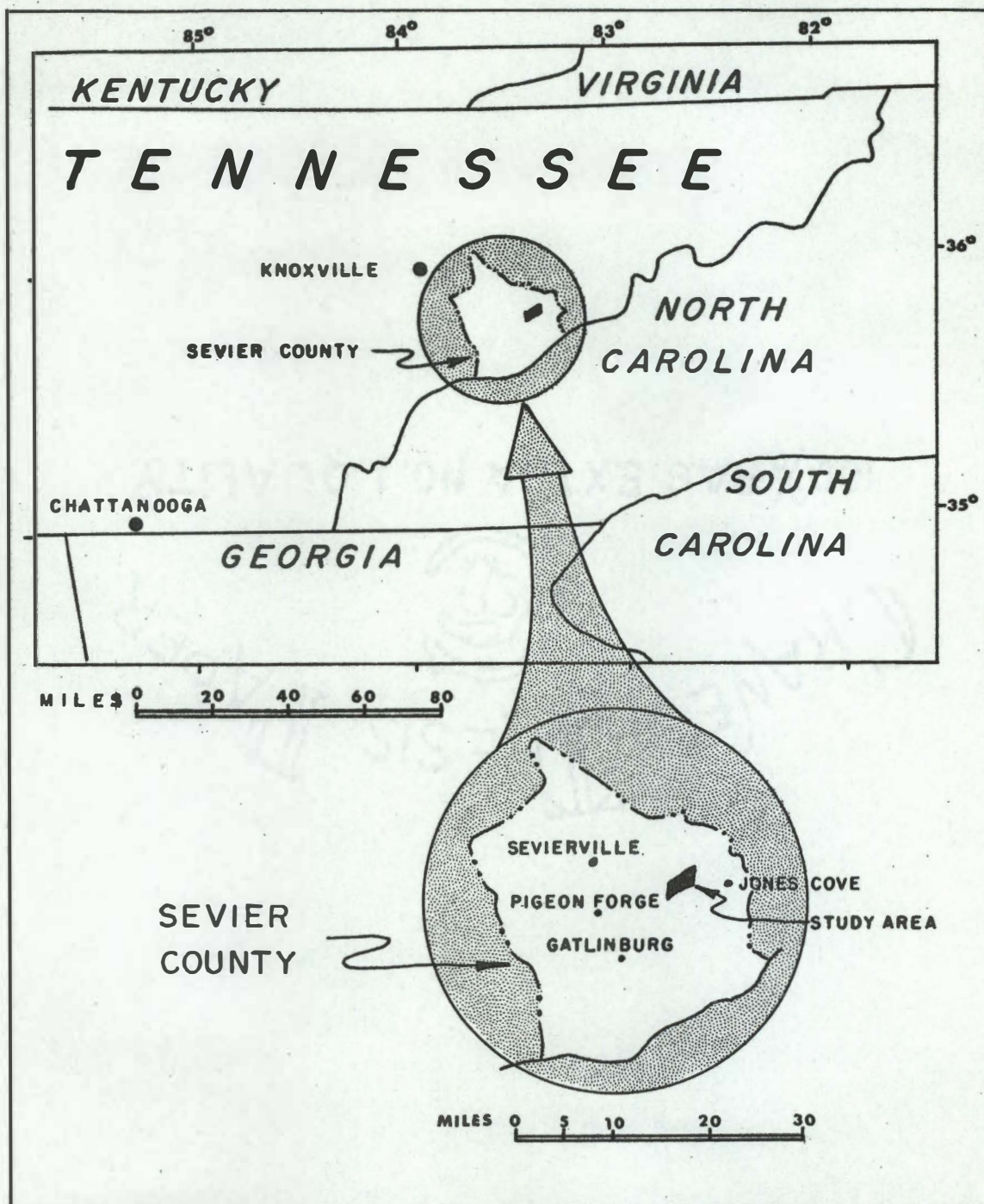


Figure 1. Location of the study area.

Investigation Purpose and Scope

The purpose of this study is to describe the geology and mineralogy of the East Fork manganese mine, and to determine its relationship to local geology. To accomplish this, it was necessary to map the thesis area at a nominal scale of one inch equalling 500 feet, and the mine area at a scale of one inch equalling 50 feet. In addition, 146 hand specimens were collected and examined under the hand lens and binocular microscope. Thin sections were cut from 20 specimens and examined under the petrographic microscope; four were examined further under the electron microprobe. Forty-four rock samples and 10 standards were analyzed for manganese and phosphorus content by means of X-ray fluorescence, abbreviated below as "XRF."

Previous geologic mapping in Sevier County has dealt with mapping of the geology of East Tennessee and the adjacent states, and has not focused on the geology of the East Fork mine area. The one exception to date is the work of Hamilton (1961) that is related to the bedrock mapping program of the U.S. Geological Survey in the Great Smoky Mountains National Park. This paper includes a bedrock geologic map at a scale of 1:24,000, stratigraphic description, and several structural sections. However, the validity of some of the units, and hence, their location and structure is still open to question because it is difficult to distinguish some of the formations and their suggested members. In particular the field identification of suggested divisions of the Wilhite Formation is very uncertain. The Dixon Mountain Member, Upper Yellow Breeches Member, and Lower Yellow Breeches Member cannot be distinguished by this writer. Also, rocks at outcrops of those

suggested units appear similar to some outcrops of the Slate of Richardson Cove, as designated by Hamilton (1961, Plate 1). However, the general interpretations of Hamilton (1961) are consistent with those of the writer, and do provide a starting point. The writer has taken the approach of mapping lithologic boundaries rather than of trying to sharpen the map definitions of the formations and members as presented by Hamilton (1961). It is felt that the lithologic relationships are of prime importance.

Earlier studies conducted at the East Fork mine have been concerned mainly with problems of ore quantity and grade. Those studies, conducted mainly by investigators from the Tennessee Valley Authority (T.V.A.), and Stose and Schrader (1923), have involved a few polished sections, numerous wet chemical analyses, and some rough diagrammatic structure sections through the mine cuts. The studies include conjecture as to origin of the ore, based on observations made in the mine cuts. But a detailed systematic study of the ore deposits as related to the geology of the mine cuts and the surrounding area has not been made. Earlier studies also have not explained the relationship of nearby phosphorite deposits to the manganese occurrences and to local geology.

Physiography

The study area is in the Foothills belt of the Great Smoky Mountains (Hamilton, 1961, p. A-3). The area is characterized by steep slopes, sharp peaks and divides, and narrow valleys (Plate 1). Short slopes of 30 to 40 degrees are common. Three peaks are prominent. They are: Bearwallow Mountain, Short Mountain, and Dixon Mountain. The highest

elevation, approximately 1,965 feet, is on Short Mountain. Dixon Mountain reaches approximately 1,880 feet, and Bearwallow Mountain crests at 1,800 feet. The lowest point is 1,020 feet, where Dunn Creek flows out of the northern portion of the area (Plate 1). The major drainage is Dunn Creek, referred to by Stose and Schrader (1923, p. 102) as the East Fork of the Little Pigeon River. The two next largest streams are Long Branch, draining westward into Dunn Creek at the northern boundary, and Dockery Branch, draining north into Dunn Creek near the southeastern corner. The other named streams, Mize Branch and Mill Branch, are both at the southern boundary (Plate 1). Mize Branch drains easterly into Dunn Creek, and Mill Branch drains west into the Little Pigeon River. In addition to the named streams, nearly every small valley supports a first order tributary.

Vegetation is heavy and most slopes are covered with brush, saplings or briars, implying wood cutting activities or brush fires in the past. There are also scattered thickets of pine saplings usually growing on sandy soil derived from underlying metaconglomerate, meta-sandstone, or sandy metasiltstone. Bottomlands, if not under cultivation, are overgrown with grass and briars. Cultivation in the past was much more extensive on both hillslopes and bottomlands. The area now supports only a few gardens, corn fields, or tobacco patches. Due to dense vegetation, cultivation and soils produced by weathering, rock outcrops are scarce. Even on steep slopes the bedrock is typically concealed beneath a mantle of colluvium.

Geological Setting

Rocks in this portion of the Foothills belt lie in the chlorite zone of very low grade metamorphism (Hamilton, 1961, p. A-36). Metamorphism has been sufficient to induce slaty cleavage in some of the units and to have formed metaquartzite, which outcrops in the northern portion of the study area. A typical exposure is indicated on Plate 1 at sample location 58. Detailed lithologic descriptions are in the Appendix. In general, metamorphism is so slight that sedimentary rather than metamorphic nomenclature best describes the lithology.

One of the northern corners of the study area (TRC 2,774,700E, 539,900N) lies close to the Great Smoky fault, which is 0.6 miles away, to the northwest. Thus, the study area lies entirely southeast of the Great Smoky fault. In general, the areal geology can be described as consisting of metasedimentary units that strike approximately N.60°E and dip steeply southeast, generally 50 to 70 degrees (Plate 2, in map pocket). Extensive small-scale folding and faulting is evident, and two larger thrust faults occur in the southern portion of the study area. The northern portion of the area is dominated by sandstone, the middle by pelitic units ranging from siltstone to poorly developed slate. A northeast striking narrow carbonate unit crosses the west-central portion of the pelitic units and crops out on Dixon Mountain in the eastern portion of the area (Plate 1). The southern portion is predominantly a band of metaconglomerate that is truncated by the Dunn Creek fault. The upthrown block of siltstone and slate exhibits a scarp that approximates the southern boundary of the study area. From

the scarp southwards, the siltstone and slate persist for many miles into the Great Smoky Mountains (Hamilton, 1961, Plate 1).

Previous Regional Geologic Studies

The structure and stratigraphy of the Ocoee Series and its age and relationship to other units has been the subject of many investigations and arguments from the time of its description by Safford (1869, p. 182-98). The reader is referred to Hamilton (1961, p. A-2, 3) for a brief summary of the literature on the Ocoee Series.

This portion of the Great Smoky Mountains was mapped by Arthur Keith (1895, 1903) as part of the Geological Atlas project. The study area is in the Mt. Guyot quadrangle that was mapped by Keith but never published in the folio series. However, the adjacent quadrangles on the east and west were published; the folio to the west is the Knoxville Folio (Keith, 1895) and the Asheville Folio (Keith, 1903) is to the east. In the text of the Knoxville Folio (Keith, 1895, p. 2) refers to limestone and limestone conglomerate in the Wilhite Slate, named for Wilhite Creek near the present study area.

Regarding the Ocoee Series in general, a review of the literature shows that most geologists consider it to be Late Precambrian in age and lying stratigraphically immediately beneath the Chilhowee Group. Both the assumptions of age and stratigraphy are still open to further study.

Inasmuch as the Dunn Creek fault forms an important part of the structural interpretation of the study area, the writer feels that it is important to substantiate its existence. The earliest map known to

to the writer that indicates the Dunn Creek fault is in King (1949, p. 626). The article by King (1949) is essentially a preliminary report on the work then underway by the U.S. Geological Survey in the Great Smoky Mountains near Gatlinburg. The map printed in this article shows several unnamed faults, one of which is unmistakably the Dunn Creek fault. In Rogers (1953) there are several illustrations that show the Dunn Creek fault named as such. Figure 5 in Rogers (1953, p. 126) shows the Dunn Creek fault as part of the complex fault system of East Tennessee. Plate 10, the map of the Mt. Guyot quadrangle in the map pocket of Rogers (1953) shows the Dunn Creek fault in greater detail.

CHAPTER II

STRATIGRAPHY

Broad Relations

The rocks in the study area are marine sediments belonging to the Ocoee Series (Figure 2) of Late Precambrian (?) age. Most of the study area is underlain by rocks of the Walden Creek Group, represented by the Wilhite Formation in the north and central portions and the Shields(?) Conglomerate in the south. A vast area lying south of the study area (Hamilton, 1961, Plate 1) is underlain by the Pigeon Siltstone of the Snowbird Group, but the southern edge of the study area includes only a narrow belt of Pigeon Siltstone.

Sharp contacts between rock units in the study area are rare, and lenses or zones of one rock type are commonly found in a unit of different lithology. Thus, sandstone lenses occur in shale units, shale lenses occur in conglomerate or sandstone units, carbonate lenses occur in both shale and sandstone units, and vice-versa. In addition, the clastic units exhibit gradational changes in grain size both laterally and vertically; consequently similar lithologies may be in fault contact with each other. Weathered outcrops of the pelitic units, and weathered float, all exhibit a uniform light brown (5YR5/6) laminated appearance. Taken together these conditions create uncertainty as to the precise location of unit boundaries in several instances. In the descriptive sections that follow, grain size classification is according to Wentworth scale nomenclature. Where a grain diameter is stated, it refers to the maximum diameter, measured along the a-axis;

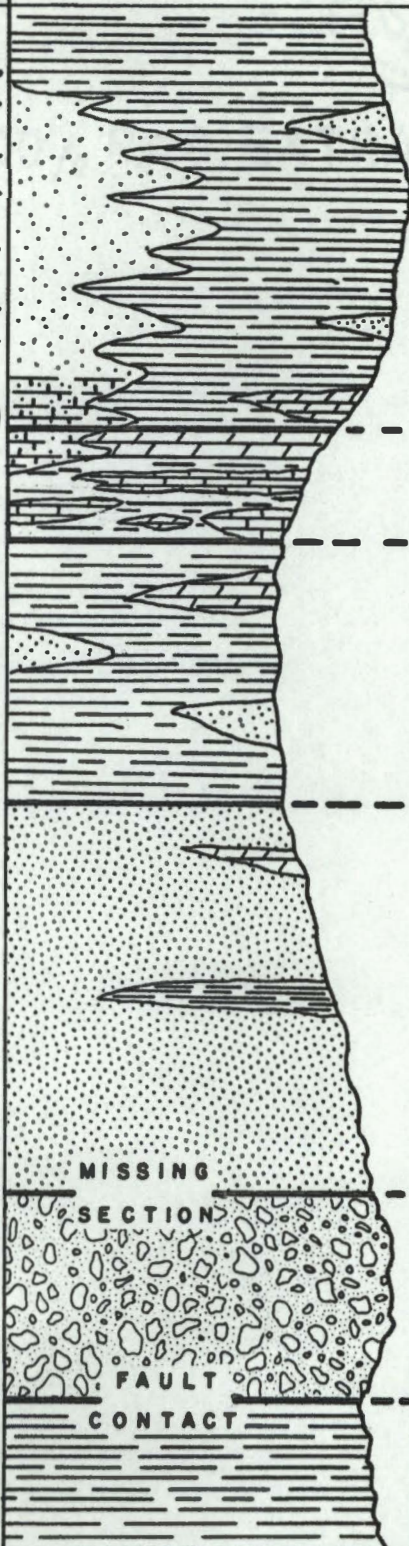
AGE	LITHOLOGY	THICKNESS	DESIGNATION
LATE PRECAMBRIAN		PARTIAL SECTION 3,000'	SLATY SILTSTONE UNIT
		875'	CARBONATE UNIT
		2,000	LOWER SILTSTONE UNIT
		3,000'	SANDSTONE UNIT
		MISSING SECTION	SHIELDS? CONGLOMERATE
		FAULT CONTACT	PIGEON SILTSTONE
		PARTIAL SECTION	
WILHITE FORMATION			
WALDEN CREEK GROUP			
OCOEE SERIES			
			SNOWBIRD GROUP

Figure 2. Generalized geologic column for the study area.

where a second diameter is stated, it refers to a measurement along the intermediate, or b-axis, and similarly, a third measurement refers to the c-axis. Bedding terminology follows that of Ingram (1954, p. 938), and color descriptions follow the Geological Society of America Rock-Color chart (Goddard, 1970). The term "MnO" is used in the general sense to mean "manganese oxide," and not to indicate a specific manganese mineral.

Lithologic Unit Descriptions

Pigeon Siltstone

The Pigeon Siltstone is dark gray (N3) to greenish black (5G2/1) on fresh surfaces, light brown (5YR5/6) on weathered surfaces and exhibits the best developed slaty cleavage of any unit in the study area (Plate 1). The rock is easily parted along bedding and cleavage surfaces, yielding sharp-edged plates or chips. The rock is finely laminated, with laminae thickness ranging from 0.25 to 3.00 mm. Dark colored laminae are very fine-grained sand; the light laminae are silty. Mica flakes are abundant throughout. Cleavage planes are generally marked by a mica sheen. Sedimentary structure consists of microlenses and crossbeds, accentuated by the light and dark laminations. The dark sandy bands tend to be somewhat thicker than the light, ranging to 5 mm. The thinner, silty bands range up to three millimeters in thickness, but probably average about one to one and one-half millimeter.

This unit has been intensely deformed on a local scale, but still exhibits a regional northeasterly strike and a southeasterly dip on the order of 50° to 65°. At the mouth of Dockery Branch (southeast corner, Plate 1), the unit is essentially horizontal. Cleavage generally strikes

parallel or subparallel to bedding and also dips steeply southeast. Many exceptions to the general attitude of bedding and cleavage can be found. The outcrop of the Pigeon Siltstone in the study area forms a steep straight scarp along the south side of the Mill Branch, Mize Branch, Dunn Creek alignment, and the stream alignment marks the fault contact between the Pigeon Siltstone and the Shields(?) Conglomerate. The scarp is quite steep; slopes of 40° are common. However, the slopes are deeply weathered and although float is abundant, bedrock exposures are not.

Shields(?) Conglomerate

The type locality of the Shields Conglomerate is Shields Mountain, about one mile away from the study area to the northwest, but the conglomerate on Short Mountain is not contiguous with the Shields Conglomerate. Hamilton (1961, p. A-19, 20) correlates the conglomerate on Short Mountain with the Shields Conglomerate on the basis of lithologic and stratigraphic similarity, plus structural considerations. The writer considers this correlation to be correct and retains the designation of Shields(?) Conglomerate used by Hamilton (1961).

There is considerable lithologic variation within the unit over short distances. In general, the unit is conglomeratic in the west and grades east into coarse-grained sandstone and then fine-grained sandstone. All variations are medium dark gray (N4) on weathered surfaces, and moderate yellowish brown (10YR5/4) or medium gray (N5) on fresh. The yellowish brown coloration may be due to limonite staining or the presence of clay minerals as alteration products.

The conglomerate is composed of quartz grains, orthoclase and dark silt matrix. Quartz grains range from one-half to four millimeters in diameter; colors range from clear to milky, and shapes range from angular to round. Grains larger than 3 mm tend to be more rounded. Quartz grains typically constitute 40 to 50% of the rock, and feldspar less, typically 20 to 40%. Feldspar occurs as euhedral to subhedral grains commonly in the 3 to 8 mm range, but one very large grain measuring 12 by 9 mm was seen. Most feldspar grains are crumbly and deeply weathered. The presence of feldspar in weathered conglomerate is sometimes indicated by angular cavities filled with white clay.

Larger clasts in the conglomerate are mainly rounded quartz pebbles ranging up to 20 mm but typically are in the 5 to 10 mm range. Flat chips of slate are also common, and range from those barely discernable under a hand lens to some that measure 25 mm across. In a few places indications of cross-bedding can be seen. At most outcrops exposure is not sufficient to permit the measurement of bedding, but at some outcrops it ranges from 2 to 10 feet thick.

At the eastern end of the Shields(?) Conglomerate outcrop the unit grades into coarse to medium sandstone. Exposures on the south bank of Dunn Creek 300 feet downstream from Pearl Valley Church (TRC 2,781,100E, 530,800N) are of medium-grained sandstone in beds one-half to two feet thick, in places separated by slaty partings to four inches thick. Within 500 feet due south from that point the rocks have graded into fine-grained sandstone, and within 1,000 feet, into sandy siltstone. On the knob 500 feet north of the above coordinates and hence lower stratigraphically, coarse- to medium-grained sandstone occurs, containing rounded white quartz pebbles up to 20 mm. Fractures filled

with clear or milky quartz, and also open fractures containing cockscomb quartz, are common throughout the Shields(?) Conglomerate.

Sandstone Unit

This unit plus the two siltstone units described below comprise in part the Dixon Mountain Member of Hamilton (1961, p. A-21, 23), which is not used in this study for reasons described in the introductory section on page 3. The rocks of this unit range from sandy siltstone to coarse-grained quartzose sandstone, and also contain slate partings. Weathered surfaces appear grayish orange (10YR7/4) or light gray (N7). Unweathered samples are extremely tough and shear through the quartz grains, exhibiting typical quartzite characteristics. However, bedrock exposures are usually deeply weathered and the rock is easily broken. Excellent exposures of a partial section can be seen along a dirt road beginning at Bethany Church at the northern corner of the study area (TRC 2,774,900E, 539,400N) and continuing south along Dunn Creek. From north to south, that is, from stratigraphically low in the unit and continuing towards the top, sediments grade from sandy siltstone into very coarse sandstone at the center, and then into siltstone and sandy shale near the top.

Exclusive of the silty top and bottom portions of the unit, the rock consists of 75 to 80% angular to subround quartz grains, milky or clear in color. Grain size is predominantly in the 0.25 to 1.00 mm range (medium to coarse sand) with a few grains, perhaps 10 to 15%, as large as 2 or 3 mm. Most of the unit is characteristically thin to medium bedded (Figure 3), with bedding being thickest near the center, where beds range to 2 feet thick. Beds are laminated, with laminae

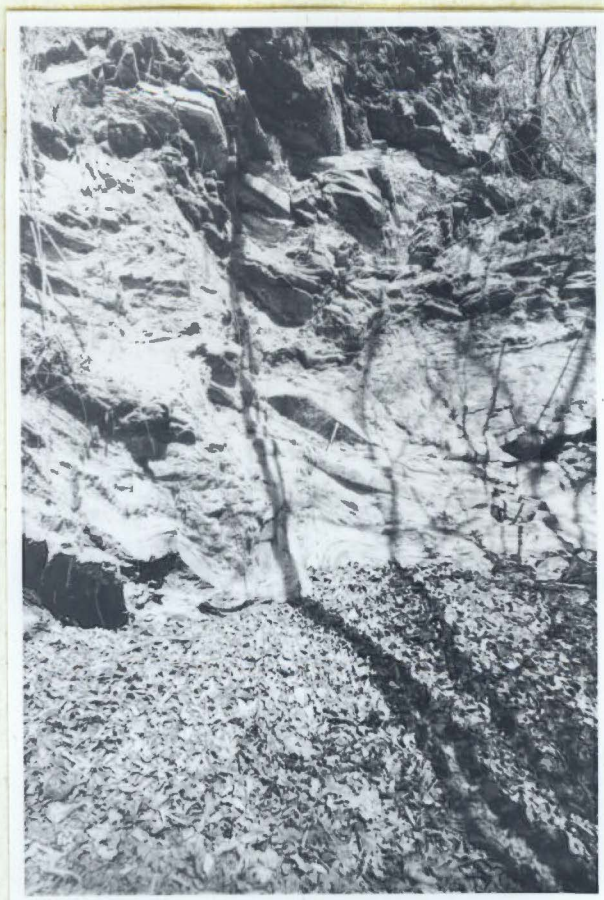


Figure 3. A cliff formed of bedded sandstone. View is northeast. Location is at TRC 2,772,500E, 534,450N. Note the geologic hammer at the center for scale.

ranging from 1.0 to 10 mm, but most are in the 1 to 3 mm range.

Small-scale cross-bedding is displayed at an outcrop located on the east bank of Dunn Creek at TRC 2,774,300E, 535,400N (Plate 1). At this outcrop grain size is in the very fine to fine range. Beds are 8 to 10 inches thick, and individual laminae are 1 to 10 mm thick; most are in the 1 to 3 mm range. Shale partings to 2 inches thick are present in the northern portion of the exposure, near Bethany Church and also at TRC 2,774,750E, 537,250N, where the beds dip 18° to the south.

The sandstone unit has a regional northeasterly strike and southeasterly dip. Local deformation has been intense in places, as

indicated by the changing attitudes along the above-mentioned road; therefore, thickness determinations are uncertain. The maximum thickness of the partial section described above appears to be 3,000 feet, as indicated in Figure 2, p. 10.

Lower Siltstone Unit

This unit conformably overlies the sandstone unit, and is exposed on the southeast flank of Bearwallow Mountain. The carbonate unit described below occurs stratigraphically above this unit and is in part interbedded with it. This siltstone is generally dark yellowish orange (10YR6/6) to dark yellowish brown (10YR4/2) on fresh or weathered surfaces, and is earthy appearing and friable. It is laminated in layers ranging from 0.5 to 2.0 mm and the laminae commonly are distorted. Several lenses of medium- to coarse-grained sandstone are present, measuring up to 100 feet thick. Near the stratigraphic top of the unit at the western end of the study area the sediments resemble turbidites and consist of thin bedded siltstone, shale, sandstone, and conglomerate. Quartz grains in those units range from 0.5 to 3 mm in diameter and are subangular to rounded.

Carbonate Unit

This unit corresponds to the Yellow Breeches Member of the Wilhite Formation (Hamilton, 1961, p. A-23-26). This writer has found that the division into upper and lower units as proposed by Hamilton (1961, p. A-24) is not workable for the study area. A section through the carbonate unit is best displayed in the valley between Bearwallow and Short Mountains. Elsewhere the section thins out or is too distorted to display a complete section. The unit consists of an irregular series

of lenses and pods of carbonate conglomerate. That series is capped in the western portion of the study area by a laterally persistent dolostone bed (Plates 1 and 2, map pocket). In some places there are several feet of shale separating the lensed portion of the unit from the dolostone cap. Other outcrops of dolostone, separated from the persistent cap, appear along strike to the northeast in the sandstone unit, and to the southeast in siltstone. In the eastern extremity of the study area on Dixon Mountain, the dolostone cap does not exist, and the carbonate conglomerate grades upward into calcareous sandstone. Dolostone lenses are interspersed among the carbonate conglomerate lenses and siltstone lenses in both the western and eastern portions of the study area.

On Dixon Mountain some of the more massive lenses form outcrops in which the texture of the carbonate conglomerate is clearly shown. Figure 4 illustrates part of an edgewise conglomerate lens typical of



Figure 4. Edgewise conglomerate on Dixon Mountain. Outcrop is located at TRC 2,778,300E, 535,000N. Note pencil for scale, and bent strip of muddy limestone.

lenses in the carbonate conglomerate unit. Pettijohn and Potter (1964, plates 15A and 105A) illustrate similar lithology in Cambrian and Ordovician shallow-water limestone conglomerates in Maryland.

On the weathered surface the more homogeneous limestones and dolostones of this unit have a uniform light olive gray (5Y6/1) appearance. Color of fresh surfaces ranges from light gray (N7) to pale yellowish brown (10YR6/2). Fresh surfaces have a sugary texture continuous across clasts and matrix alike. Therefore, conglomeratic composition is not evident on fresh surfaces, but wetting the surface may make it visible. Weathering accentuates relief between grains in the sandy matrix, and brightens the strips and pebbles of muddy limestone. The matrix material is very fine-grained calcareous sandstone. Although most grains average less than 0.1 mm, a few rounded quartz grains reach 3 mm in diameter. Larger clasts in the conglomerate are mainly strips of calcareous mud or silty limestone. Figure 4 shows that some of the clasts are deformed while still soft. Other clasts are chips of slate of various sizes, but usually less than 25 mm long. At an exposure in the Dunn Creek valley 700 feet west of Pearl Valley Church, at TRC 2,780,700E, 531,000N, some clasts consist of round pebbles of dark reddish brown (10R3/4) sandstone 10 mm in diameter. At this exposure (Plate 1), the unit is more sandy and has larger clasts than elsewhere, indicating a higher-energy environment. Contrarily, in the western part of the study area carbonaceous limestone and clean, silt-free limestone occur. A small outcrop of massive black, clean limestone, representing a lens in the middle of the carbonate unit, is seen at TRC 2,769,500E, 530,500N on an east-facing hillslope. On fresh surfaces

the rock has a sugary texture due to its crystallinity. It exhibits a sub-conchoidal fracture. This outcrop represents a low-energy environment into which very little clastic material was being deposited.

Dolostone lenses and carbonate conglomerate lenses interfinger with shale and siltstone throughout the carbonate unit below the dolostone cap, indicating rapidly changing conditions. Such lensing is traceable for 500 feet southeast from the above coordinates, and northeast for 2,600 feet. This part of the carbonate unit appears to lens out suddenly in both the southeast and northeast directions, yielding to siltstone.

Black to gray argillaceous limestone occurs stratigraphically only a few feet under the dolostone cap at two places, sample locations 81 and 86 (Plates 3 and 4, map pocket). Location 86 is in a brook at TRC 2,771,500E, 531,860N. There the limestone is very argillaceous and black, appearing almost graphitic. Laminations range from 2 mm to 5 mm and are slightly undulating. At location 81, downstrike 1,300 feet from 86, the black limestone is much less argillaceous and laminae are thicker, ranging from 1 mm to 20 mm. Approximately 800 feet southeast from location 81, on the south side of the roadway where beds dip 42° , another carbonaceous outcrop occurs. Small irregular black limestone plates and chips ranging from 5 to 15 mm thick, and somewhat bent and distorted, are separated by selvages of carbonaceous shale (Figure 5), suggestive of slumping. A change in the sedimentary environment from deeper water to shallow water or supratidal conditions is suggested by the presence of a dolostone bed averaging 50 feet thick and continuous for 5,000 feet along strike. Similar to the carbonate conglomerate described above, the dolostone also lenses-out suddenly.



Figure 5. Carbonaceous limestone and shale partings.

In the southwest it yields to siltstone and to the northeast to sandstone. To the northeast, entirely within the sandstone unit, but exactly on strike with the continuous bed; four other small outcrops of dolostone occur. One outcrop (Plate 1) is at TRC 2,774,500E, 535,350N. Another occurs 400 feet to the northeast at TRC 2,744,800E, 535,600N, and two others occur at TRC 2,775,700E, 536,600N. To the southeast, on strike with the others, three more small outcrops occur. The nearest one is a limestone outcrop at TRC 2,768,000E, 528,200N, near a cemetery. A dolostone outcrop occurs in the southwest corner of the study area at TRC 2,776,100E, 526,950N, where laminae in the dolostone indicate a vertical dip. To the south, 300 feet from the above outcrop, limestone, similar to that described at location 81, dips steeply to the southeast. Because of the lithologic similarities, but mainly because of the fact that all of these outcrops occur on strike, the writer believes

that they represent a stratigraphic horizon and therefore aid in understanding the local structure and stratigraphy.

In general the dolostone is very well indurated, appears light olive gray (5Y6/1) on weathered surfaces and light gray (N7) on fresh. Fresh surfaces exhibit a sugary texture due to the uniformly small grain size, less than 0.1 mm. On fresh surfaces laminae cannot be detected but weathered surfaces at a few outcrops show laminae ranging from 1 to 5 mm in thickness. Distinct bedding is not seen, but the blocky nature of some outcrops suggests bedding on the order of 1 to 2 feet thick. Silt-sized pyrite specks are disseminated throughout the dolostone and limestone. In a few samples, small clusters of pyrite specks are easily seen with a hand lens. Small veinlets of quartz or calcite up to 2 mm thick are common. Except for a sandstone lens at TRC 2,771,100E, 531,300N, the dolostone is underlain by limestone conglomerate or siltstone as far to the east as Dunn Creek. From that point on, it occurs within the sandstone unit. Immediately east of the East Fork mine, the dolostone is overlain by a large feldspathic graywacke lens that contains phosphorite deposits. The graywacke is very well indurated, and consists of 35% angular quartz grains, 25% weathered feldspar, 30% black silty matrix, and 10% disseminated pyrite. Quartz grains range up to 2 mm, and feldspar to 1 mm. A similar outcrop (Plate 1) occurs in the bed of Dunn Creek at TRC 2,775,000E, 533,750N, where it causes ripples in the water. Within the sharp bend of Dunn Creek the dolostone is overlain by siltstone, yielding to sandstone towards the east.

At the stratigraphic top of the dolostone and probably for several feet below it, there are pods of manganese ore. They are now mined-out,

but open cuts remain. The manganiferous area (Plates 4 and 5) is bounded on the west by TRC 2,771,500E, and on the east by TRC 2,775,000E. Location of the manganese workings and unproductive prospects are shown in detail on Plates 3, 4, and 5 in the map pocket.

As indicated earlier, the persistent dolostone bed averages 50 feet thick. But at the northeastern end in Dunn Creek it is 135 feet thick. The carbonate conglomerate interfingered with shale reaches a maximum thickness of 500 feet near its western end. Maximum thickness of the entire unit, from the base of the conglomerates to the top of the dolostone is 875 feet. Where structure section C-C' (Plate 2) cuts the area, thickness is 620 feet.

The carbonate conglomerate occurrences on Dixon Mountain merit a separate description because they differ from the western exposures in several respects. They are much more variable, both laterally and vertically. Persistent beds that can be mapped with certainty exist only at the western edge of the outcrop area (Plate 1). The topmost two to four feet of a dolostone conglomerate bed is exposed (Figure 6) in that area and can be traced with certainty. It is overlain by a limestone conglomerate bed with exposures up to 10 feet thick (Figure 7). The outcrop belt of this pair wraps around part of the mountain at two different locations, for 1,000 feet in each case, and the outcrops terminate abruptly. Beds or lenses of massive carbonate are absent; carbonate conglomerate is the rule. But areas underlain by large outcrops of carbonate conglomerate grade quickly into highly calcareous sandstone. In addition, there are lenses of quartzose sandstone, siltstone, and shale. One sandstone lens contains phosphorite (TRC 2,779,700E, 534,850N), and appears to be near the stratigraphic top of



Figure 6. Dolostone conglomerate outcrop on Dixon Mountain. Location is at TRC 2,777,450E, 533,950N. Note the 6 inch ruler.



Figure 7. Thickly bedded carbonate conglomerate. Located on Dixon Mountain at TRC 2,777,600E, 535,900N. Note orange handle of geologic hammer for scale, lower left-center.

the carbonate unit, somewhat analogous to the phosphorite occurrences near the East Fork mine. Thin sections from the Dixon Mountain outcrop and the easternmost outcrop at East Fork (Plate 5) are also similar.

Bedding attitudes in the central portion of the Dixon Mountain area are chaotic and therefore not reliable in determining stratigraphy. However, there is a clear lithologic trend from east to west. Fine to medium-grained sandstone dipping southeast grades westward into calcareous sandstone and then into carbonate conglomerate. The base of the conglomerate unit is marked by a laterally persistent limestone-dolostone pair, with the dolostone, conglomeratic in places (Figure 6) being lowermost. Regarding the carbonate conglomerate unit across the study area as a whole (Plate 2), it is indicated that there is a change from the west towards the east into a higher energy depositional environment.

Slaty Siltstone Unit

The slaty siltstone unit conformably overlies the carbonate unit in the western part of the study area, and forms most of Short Mountain and the western flank of Dixon Mountain. The best exposures occur at the east end of Short Mountain along the road and in the creek bed. Excellent exposures also occur along a road leading up Dixon Mountain starting at TRC 2,776,900E, 531,800N. This unit is resistant to erosion and forms sharp ridges and steep slopes. Locally, slopes may reach a steepness of 45°.

This unit is lithologically similar to the Pigeon Siltstone and would be difficult to distinguish if the two were in contact. Overall,

the rock on fresh surfaces appears dark gray (N3). Weathered surfaces are brownish gray (5YR4/1) to grayish orange (10YR7/4). Cleavage is much more developed than in the lower siltstone unit (Figure 8). Slopes are commonly covered with weathered chips that obscure the underlying bedrock. The rock is generally well indurated and a few outcrops yield cleavage plates that give a typical slaty "ring" when struck. Grain size is small, averaging less than 0.1 mm. Mica is abundant along bedding and cleavage planes. Small flecks of limonite are abundant throughout.

Laminations range from 0.25 mm to 10 mm with most laminae being in the 1 to 5 mm range. Dark laminae tend to be sandy and thicker than the light colored laminae, which tend to be silty, as in the Pigeon Siltstone. In some of the thicker dark laminae, there is cross-bedding. Bedding on a larger scale was not measured directly, but at some outcrops where cleavage is poorly developed, the rocks tend to part along laminae into 2- to 4-inch blocks, suggesting bedding on that order.

From the west towards the east, this unit becomes slightly more sandy. At the eastern end of the unit, on the north flanks of Dixon Mountain, the unit is a very fine-grained sandstone or coarse siltstone. The writer believes that a facies change is indicated across the study area, because the carbonate unit is conformably overlain by slaty siltstone in the western portion and by sandstone on Dixon Mountain.

In addition to sand, clay-sized material was also being transported into this depositional basin, as evidenced by shale lenses in the sandstone and carbonate sediments. Two outcrops are particularly notable for the clean quality of the shale. At the crest of a spur on Dixon Mountain at 2,778,100E, 534,700N, is an outcrop of very clean yellowish



Figure 8. Slaty siltstone outcrop at bend in Dunn Creek. Located at TRC 2,775,200E, 533,700N. Cleavage is parallel to bedding. Joint set dips 46° southeast. Scale is shown by a camera sitting on a notch in the outcrop at center of photograph.

gray (5Y7/2) micaceous shale (Figure 9). Slaty cleavage is well developed at this location, and the shale is micaceous and free of sand grains. Another shale lens outcrops on the east side of the southward facing valley on Dixon Mountain, at TRC 2,780,000E, 535,200N. Here the shale is slightly sandy, very light gray (N8) in color, and is earthy and crumbly. Laminations average 0.5 mm thick. The sandstone phase of this unit becomes increasingly coarse towards the top. Basal portions are in the very fine sand to fine sand range, and the upper portions are coarse to very coarse. The fine-grained phase is laminated; the laminae range from 0.5 to 6.0 mm. Some outcrops of the fine phase show tight folding of the laminae. The coarse phase contains from 5 to 15%

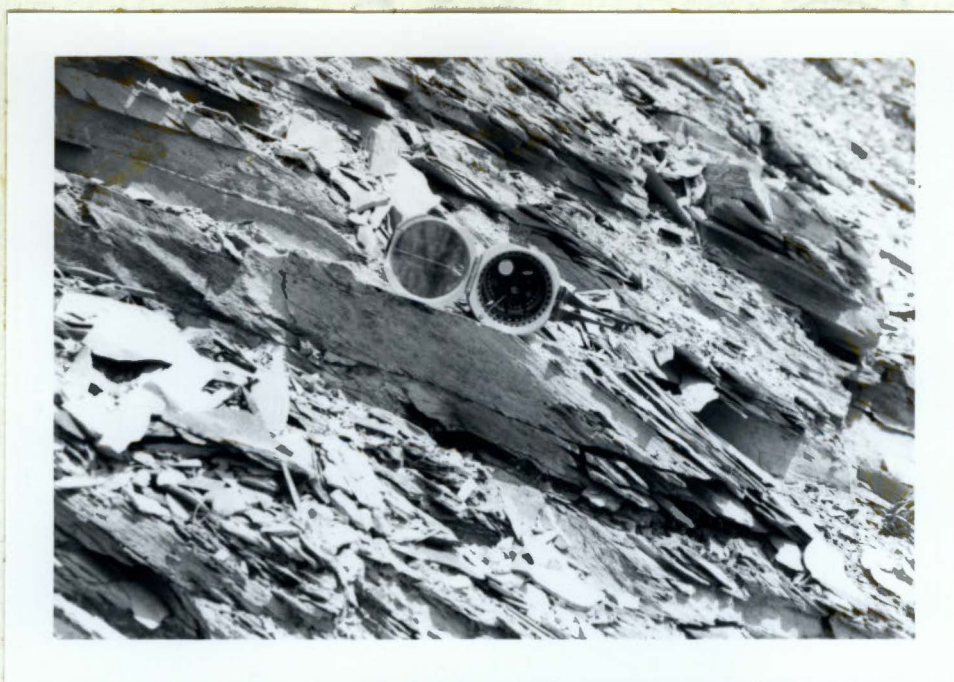


Figure 9. Micaceous shale outcrop on Dixon Mountain. Brunton compass is resting on a bedding plane that dips 20°S . Cleavage is slightly oblique to bedding, dips 45°SSE .

feldspar, usually deeply weathered and altered to clay. Quartz grains are subangular to round, and constitute up to 85% of the rock. Limonite is common, forming up to 25% of the rock, as yellow, punky masses in the interstices between the quartz grains. The abundance of limonite and altered feldspar gives the rock a pale reddish brown (10R5/4) color on weathered surfaces. Fresh surfaces generally are light gray (N7).

CHAPTER III

STRUCTURE

Regional Structural Setting

The study by Hamilton (1961) covers two quadrangles that were included in the U.S.G.S. program to map part of the Great Smoky Mountains. He therefore deals with broad structural interpretations that also include the study area of the present writer. Hamilton (1961, p. A-35) interprets the Snowbird Group as forming

. . .a complex synclinorium with, in general, a low plunge N70°E. . . .The structure of the Walden Creek Group is also broadly synclinal toward N60°E.; this northern synclinorium is truncated obliquely on the south, and separated from the synclinorium of the Snowbird Group by the eastward-trending Dunn Creek fault.

The interpretation of the structure of the study area by the writer (Plate 2, map pocket) conforms to the general interpretations of Hamilton (1961, Plate 1). That is, the study area structurally could be on the north limb of a faulted synclinorium. The writer differs with the positioning or existence of some of Hamilton's (1961) inferred contacts and faults.

Structural interpretation is hampered by intense small scale folding, as indicated by the numerous folds mapped along Dunn Creek road south of the East Fork mine, where exposure is continuous. Fold radii are on the order of a few feet, as shown by the tight folds in sandstone at the loop in Dunn Creek (Figure 10). Exposures generally are limited in extent and therefore an isolated observation might be misleading by representing part of a tight fold rather than regional attitude.

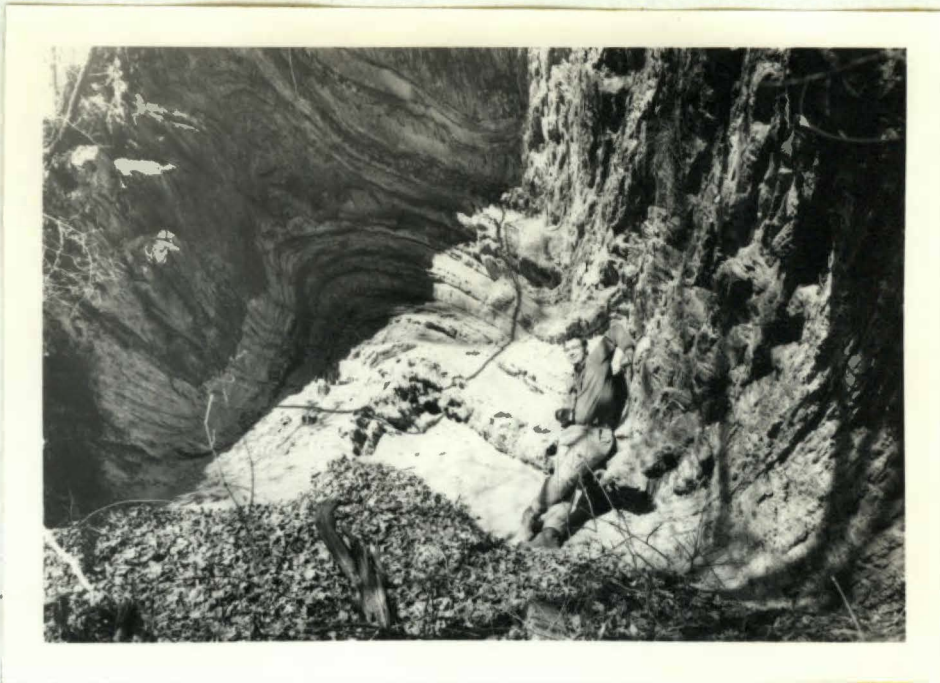


Figure 10. Tight folding in sandstone. Located at TRC 2,772,450E, 534,450N. View is northeast parallel to fold axis. Axial plane cleavage is well developed.

The deformation history of the region further complicates efforts at interpretation of structure. Hamilton (1961, p. A-35) reports that the Ocoee Series was deformed three times. He states that

The first episode formed compressional features trending eastward to northeastward. The second, during which most of the Ocoee was slightly metamorphosed, resulted in cleavage striking northeast. The third episode created structural features parallel to those of the first. The first and second episodes probably occurred during early Paleozoic, and the third during late Paleozoic.

The result is that cleavage is not always genetically related to folds. It may have been imposed on existing folds. Hamilton (1961, p. A-35) also notes that "nearly all the structural features are compressional," with cleavage and axial planes generally dipping southeast.

Study Area Structure

The writer interprets the western and southern portions of the study area as having simple structure, and the Dixon Mountain area as complex. In the western portion, the conformable stratigraphic sequence strikes N.47°E. and dips to the southeast at approximately 60°. Tight local folds and small thrust faults can be observed in several road cuts. Although faulting occurs in the southern portion, the structure is still straightforward. The writer generally agrees with Hamilton (1961, Plate 1) regarding the Dunn Creek fault and Shields (?) Conglomerate thrust sheet, except that the present writer extends them farther to the east. Fault contact along the Dunn Creek fault is essentially unaffected by topography, indicating a steeply dipping fault surface estimated to dip approximately 45°. The contact at the base of the conglomerate tends to follow topography, indicating a shallow dip. Where exposures were good and map position certain, dip was determined on Short Mountain to be 20°S.E., using the three-point method. A gouge zone 2 or 3 feet thick in the underlying siltstone can be observed in two places. The best exposure is at TRC 2,766,700E, 527,200N, near a road intersection at the western border of the study area. The other location, TRC 2,779,400E, 531,700N, is in the east near Mc Mann School.

The fault surface of the Dunn Creek fault is nowhere exposed in the study area. It is covered by colluvium on the hillslopes or by alluvium in the stream valleys. Fault presence is shown by the sharp, straight east-west scarp on the south side of streams and by a distinct

lithologic change elsewhere between the Shields(?) Conglomerate on the north and the Pigeon Siltstone on the south.

The Dixon Mountain area has a very complex structure. Exposures are numerous enough to afford many opportunities to measure attitude, but not continuous enough to clearly explain problems that arise. For example, two nearby outcrops may significantly differ in strike or dip. As mentioned earlier, the writer regards the carbonate unit as serving as a stratigraphic marker bed. It is used as such in interpreting the structure in this portion of the study area. As indicated on Plate 2 (map pocket), the writer believes that the complex outcrop pattern on Dixon Mountain is the result of two or three thrust sheets overriding each other and dipping gently southeast. Both sheets were thrust from the east or southeast. The lower sheet contains a dolostone bed, found on the northwestern and southwestern lobes of the lower sheet. The dolostone thins and disappears to the east, yielding to a thicker carbonate conglomerate and calcareous sandstone. This latter assemblage was thrust westward over the lower plate, resulting in a jumbled pile of limestone and calcareous sandstone on Dixon Mountain and in the wide outcrop of carbonate conglomerate seen along Dunn Creek west of Pearl Valley Church and in scattered patches in the valley cut into the south flank of Dixon Mountain. The upper plate has several undulations, as indicated by dip reversals. Clear evidence of low-angle faulting is seen northwest of Dixon Mountain where the carbonate band is truncated at TRC 2,776,800E, 536,100N. There, a fault is marked by a sandstone outcrop exhibiting slickensides on the eastern side (Figure 11). Striations on the polished face dip south at 25°.



Figure 11. A remnant of a fault scarp. View is to the west. Note the striations, best seen at the top-center of the smooth surface, dipping to the left.

Discontinuity of the dolostone outcrop between the northwest and southwest lobes of the lower thrust sheet is due to the overriding thrust sheet or sheets. Truncation of limestone beds (dipping 25°N.) against sandstone on the south side of Dixon Mountain at TRC 2,778,500E, 533,800N is interpreted by the writer as indicating faulting. Down-slope to the southeast, sandstone lenses terminate rather abruptly on the west, although not as clearly as in the cases cited above. However, their termination fits well the thrust sheet interpretation presented above.

Small east-west high angle faults are indicated in two locations. The western edge of the lower thrust sheet is slightly offset at TRC 2,777,400E, 533,900N, as indicated by displacement of the dolostone conglomerate bed shown in Figure 6. Relative movement is determined

by the attitude of the dolostone bed. Elsewhere, faulting is indicated by slickensides in sandstone paralleling a vertical joint set and contact of the sandstone and shale. This occurs in the area of some cliffs at TRC 2,780,600E, 534,200N. Relative movement is implied by stratigraphic considerations; siltstone on the upthrown side is older than the sandstone.

East Fork Mine Area Structure

In order to accurately present the details of location, structure and stratigraphy, this area was mapped at a scale of 1 inch equals 50 feet (Plates 3, 4, and 5). The method employed was tape and Brunton compass, using base maps prepared by the writer. The first step in preparing base maps was to project the Tennessee Rectangular Coordinates (TRC) which were on the Jones Cove and Richardson Cove quadrangles (Plate 1) across the study area to provide an initial reference. These coordinate lines were then transferred to the 1 inch equals 512 feet geologic base map transparency, which is a photographic enlargement of a portion of the above mentioned quadrangles, printed on stable base drafting film. The transfer was accomplished by comparing the relationship of the TRC-lines to contour lines. The initial fit was then checked against the coordinates of surveyed points within or near the study area. Grid coordinates of these points were obtained from Survey Control Data (1947). Grid lines 500 feet apart were then plotted in the area around the East Fork mine. Next, a blank sheet of stable base drafting film 36 inches wide by 100 inches long was gridded at a scale of 1 inch equals 50 feet, with grid lines 10 inches apart, i.e., a 500 foot grid. The appropriate part of the study area was then

projected onto the large scale base map using an overhead projector so that the two grid patterns coincided. Cultural and topographic features were then traced onto the large scale map, and details were added in the field by the writer.

The manganese mine area lies in the western portion of the study area and has a basically simple structure, as mentioned earlier. A persistent dolostone bed strikes about $N.45^{\circ}E.$ and dips southeast, ranging from vertical at its far eastern end to $20^{\circ}S.E.$ near its western end. A gradual change in dip is thus indicated. The attitudes of pelitic sediments above and below the dolostone beds are less consistent. Chips and plates of siltstone showing slickensides and contorted laminae are common at the mine cuts, indicating greater deformation of the softer sediments along with the more competent dolostone. At the mine faces in cuts no. one and five (Plate 4), the ore is thoroughly sheared, indicating that it was in place at the time of deformation. East of cut no. one, in the area bounded by TRC 2,772,250E and 2,772,550E (Plates 4 and 5), the dolostone outcrop is lost for a critical 300 feet. Sediments on both sides of the dolostone in that area are overturned steeply to the northwest, and the writer assumes that the dolostone is likewise overturned. If so, the dolostone bed undergoes a sharp change in attitude at about the area of mine cut no. one, which could have resulted in extensive fracturing. The ravine at this location could be the result of the more easily dissolved fractured rock having been eroded away. Dolostone in cut no. one is more fractured than it is elsewhere and also exhibits small shoots of crumbly oxide ore up to a foot thick that pinch out quickly. Such shoots may have formed in solution channels

in the fractured dolostone. Fracturing in this cut might also be due in part to blasting operations during mining. Where the dolostone outcrops on the west bank of Dunn Creek, it has resumed the normal southeasterly dip of 80° , shown clearly by thin laminations.

CHAPTER IV

EAST FORK MINE HISTORY

Introduction

Inasmuch as most of the ore is mined out, and all that is left are overgrown, partly caved mine cuts and overgrown dumps, the evaluations made by those who visited the mine during its operation are particularly helpful. From their observations one can gain an understanding of the structural and spatial aspects of the ore body. Those observations add a great deal to the present interpretations made by the writer. The East Fork mine (Plates 3, 4, 5) as indicated in the reports cited below, was mined for iron ore in the late 1700's and then abandoned for many years. During World Wars I and II manganese ore was mined, but the mine was idle between 1918 and 1940, and again after World War II. Phosphorites occurring nearby were reported by 1940, but have never been mined.

Iron Mining

Iron ore consisted of limonite and hematite capping the manganese ore and extending partly down into it. Iron mining ceased when the manganese ore was encountered because the manganese caused smelting problems in the blast furnaces erected near the mine site. It is reported that "the original manganese miners found piles of manganese thrown out by the iron miners" (Butters, 1940, p. 3). A plan and profile in Rankin (1936, p. 4) taken from a Tennessee Manganese

Company print shows the trenches on the ridge between cuts no. one and two (Plate 4) to be iron ore pits. Massive limonite is no longer present, so the relationship between the iron ore and the manganese ore is uncertain. However, manganese ore from this mine commonly exhibits limonite and hematite stains and also contains disseminated pyrite. In a T.V.A. reconnaissance report dated October, 1940, the investigator from the Chemical Engineering Department mentions the occurrence of "a couple of feet of almost solid pyrite" in the manganese ore. The occurrence was not inspected by the investigator, but rather was the description of the mine operator, Mr. Martin, who said that pyrite was disseminated throughout the ore (Butters, 1940, p. 2).

This writer collected a specimen (EF-27) of massive pyritic quartz from the dump at the mouth of the largest mine cut, cut no. 1 (Plate 4) that could be representative of the pyrite zone mentioned above. Pyrite is common in the manganese ore and perhaps the iron ore was the weathering product of disseminated or massive pyrite. Regarding the smelting of iron ore, the writer has observed scoria-like slag on the west bank of Dunn Creek approximately 150 feet downstream from the bridge (TRC 2,773,550E, 532,750N). The slag might be from the blast furnace, and it could also be from the ore roasters mentioned in several T.V.A. reports used to up-grade the manganese ore. One such roaster was located alongside the road (TRC 2,272,300E, 531,850N) at the mouth of the ravine running between mine cuts 2 and 3 (Plate 4). The presence of the blast furnace or of ore roasters probably accounts for the fact that what is known locally as the Dunn Creek road is

called the Furnace Dam road on county records in the courthouse at Sevierville.

Manganese Mining

In the spring of 1967, Arthur Keith and G. W. Stose visited the mine to evaluate the manganese mining operations. The mine was being operated by the Tennessee Manganese Company of Knoxville. The brief description by Keith and Stose along with two photographs of mine cuts 1 and 2, plus two photomicrographs of the ore, is included in Stose and Schrader (1923). This same report minus the photographs but including some additional commentary, is found in Reichert (1942). During the 1930's and 1940's, the site was visited several times by geologists from T.V.A. The writer has referred to their reports in summarizing the history of the mine.

A sketch map in Stose and Schrader (1923, p. 103) shows that all of the manganese occurrences seen today as open cuts were known in 1917. Also, photographs of cuts 1 and 2 compare closely with recent photographs in this report, Figures 12 and 13. The numbering of the mine cuts in this report is consistent with that of Stose and Schrader (1923) and all other reports. Stose and Schrader (1923, p. 102) mention that as of their visit, only one carload of ore had been shipped. They also mention that the exploratory shaft at the mouth of cut no. 2 was being sunk at the time of their visit. The writer has interviewed a local resident who worked on the shaft. The shaft was 80 feet deep and encountered "limestone" but no ore. Reichert (1942, p. 155) reports a shaft depth of 60 feet.



Figure 12. Mine cut number 1, East Fork mine. View is to the southwest. Horizontal streak is a negative defect. Part of caved tunnel portal can be seen in lower foreground.



Figure 13. Mine cut number 2, East Fork mine. View is to the north-east. Cut is approximately 8 feet wide and 125 feet long.

The mention of only one carload of ore in Stose and Schrader (1923, p. 102) is a problem because the size of the cuts is not in accordance with only one ore carload. There was either a great deal of waste rock or else the ore was stockpiled. In any event, cuts 1 and 2 were not significantly enlarged after spring of 1917, and the other two major cuts, no. 3 and no. 4 (Figure 14) are a great deal smaller in comparison and could not have yielded much ore. Ferguson (1944, p. 1) mentions that cut no. 5 was opened in 1942-43.

There is some discrepancy as to how much ore was mined or at least shipped. Reichert (1942, p. 153) reports that one carload was shipped in 1918. However, Ferguson (1944, p. 1), referring to the mine operator, W. P. Martin (who was also a partner in the Tennessee Manganese Company) says: "According to Mr. Martin, 27 carloads of concentrates were shipped from this mine during the first World War." The writer believes that this amount could have been shipped in the remainder of 1917 after the visit of Keith and Stose.



Figure 14. Mine cut number 4, East Fork mine. View is to the north-east. Oxide ore was removed from this cut.

There is also a question as to how many tons constituted a car-load, but other data from Ferguson (1944, p. 1) may suggest an answer. He reports the following shipments: in 1941, 137 tons of ore were shipped, in 1942, one car of roasted concentrates was shipped, and in 1943, one 48-ton car of 43.32% manganese ore was shipped plus three cars of 28.76% manganese ore. Ferguson's data raises another question: How much raw ore is represented by 1 ton of concentrate? A T.V.A. lab report dated November 11, 1944, shows a 29.4 weight percent ignition loss for a sample of banded oxide ore, and 27.9% for another sample "probably containing considerable oxide" (Electrochemical Laboratory, 1944, p. 1). Lacking better estimates, the writer used the arithmetic mean of these two ignition loss figures, 28.6%, in subsequent raw ore/ore concentrate conversions. These two samples might not be representative of all of the ore at East Fork. So, the following estimates of total ore shipped are based on the assumptions of a 48-ton carload, a 28.6% weight loss on ignition, and that this same weight loss would occur in the roasting ovens at East Fork. Table I below indicates the estimated quantity of manganese ore mined at East Fork.

In terms of volume, 2,154 tons of ore, at 2,000 lbs per ton and 195 lbs per cubic foot of ore, is equivalent to 839 cubic yards of ore. The size of the excavations at East Fork seem to be consistent with this estimate, also allowing for the volume of the existing mine dumps.

Geological Reports

The first geological evaluation was by Keith and Stose in the spring of 1917, reported in Stose and Schrader (1923, p. 102-105).

TABLE I

EAST FORK MINE PRODUCTION

Year	48-Ton Carloads Shipped	Material	Percent MnO	Tons of Concen- trate*	Con- version Factor	Tons of Ore Mined
1917	1	ore	-	-	-	48*
1917-18	27	conc.	-	1296*	x1.286	1,667*
1918	1	ore	-	-	-	48*
1941	3*	ore	-	-	-	137
1942	1	conc.	38.00%	48*	x1.286	62*
1943	1	ore	43.32%	-	-	48*
	3	ore	28.76%	-	-	144*
						TOTAL 2,154

Note: (*) indicates a calculated estimate.

Source: Compiled from Stose and Schrader (1923), Reichert (1942), and Ferguson (1944).

Of particular interest are comments on the lenticular nature of the ore, which they describe as occurring in "nearly vertical beds in the [dolostone] and slate. The ore is mostly manganese carbonate, which has been altered to oxides near the surface" (Stose and Schrader, 1923, p. 103). In describing the appearance of mine cut no. 1, they note that "the ore bodies are somewhat lenticular, as is well shown in the main workings, and overlap each other horizontally and probably also vertically" (Stose and Schrader, 1923, p. 103). And, describing the ore penetrated by a 100 foot tunnel,

This ore body is lenticular and pinches out at the face of the tunnel, but a bore hole in the southeast wall showed the presence of a body of similar ore in that direction. The open cut also shows the lenticular character of the ore bodies (Stose and Schrader, 1923, p. 104):

The ore body in mine cut no. 2 is described as being four to five feet thick and excellently exposed. The description suggests a lens

"which contracts and swells and apparently pinches out entirely at the face of the lower bench" (Stose and Schrader, 1923, p. 104).

The oxide ore is described by Stose and Schrader (1923, p. 103) as psilomelane and wad that caps the carbonate ore and is the weathering product of it. In places, manganiferous clay covered the ore to a depth of 5 feet. The clay contained "small irregular masses" of psilomelane and was interpreted as being the weathering product of the enclosing manganiferous dolostone (Stose and Schrader, 1923, p. 104).

The report of Stose and Schrader (1923) indicates that the ore body and enclosing sediments are nearly vertical and that the ore occurs as overlapping pods and lenses capped by manganese oxide, or by clay that contains pieces of manganese oxide. Regarding ore genesis, Stose and Schrader (1923, p. 105) believe that manganese minerals in the dolostone unit or in the slate were dissolved by circulating ground water, and that "the manganese was redeposited as a crystalline mixture of carbonate of calcium, magnesium, and manganese in the rock adjacent to the solution channels." Stose and Schrader (1923, p. 105) mention the circulation of ore solutions along joints at the dolostone-slate contact, and that there may have been faulting, presumably implying that manganese minerals precipitated in the fractured host rock, forming a manganese concentration due to the increased surface area available for reaction. Two photomicrographs, A and B, of polished ore are presented in Stose and Schrader (1923, p. 10) as supporting evidence. Photomicrograph A shows banded black carbonate ore in part cut by a white crystalline mass that contains numerous carbonate rhombs. Photomicrograph B illustrates zoned rhombs, the zoning marked by dark bands. The rhombs are darker in the middle than at the edges. The interpretation of Stose and

Schrader (1923, p. 105) is that the central, dark portion of the rhombs is more manganiferous than the light-colored outer portion, that the crystalline nature of the ore indicates formation at depth, and that the banded, laminated material, where it fills-in between crystalline masses, shows that the banded carbonate "is undoubtedly a product of enrichment of the ore at the lower limit of the zone of oxidation."

In summary, Stose and Schrader (1923) interpret the ore genesis as involving: 1. leaching of manganiferous dolostone and slate by groundwater, 2. precipitation and crystallization of manganese carbonate at depth, and 3. secondary enrichment near the surface, presumably following uplift and erosion. The writer does not entirely agree with this interpretation.

As indicated by the T.V.A. Geological Division file cited below the next investigation at East Fork was in 1935 by Penhallegon, a T.V.A. mining engineer. Apparently his mission was to estimate the ore reserves. His calculations used the level of Dunn Creek as a local datum plane for the water table, with the ore bottoming out 50 feet above it, a five foot thick ore body, an ore weight of 195 lbs per cubic foot, and 6,135 feet of outcrop. Even with a 50 percent safety factor, he calculated a rather optimistic 300,000 tons of ore (Penhallegon, 1935, p. 1). Later estimates were even more optimistic.

Regarding the mine cross section sketches in Stose and Schrader (1923, p. 104), it is interesting to note that they show a northwesterly dip in mine cut no. two, not in accordance with the writer's observations. Furthermore, the mine shaft that was being sunk at the time of their visit starts in slate and would be on the wrong side if it was intended

to intersect ore at depth, given a northwesterly dip. However, it is difficult to determine attitude within the mine cuts, particularly at mine cut no. one, and the writer has measured a steep northwesterly dip 200 feet away to the northeast from the mine mouth.

In 1936 a thorough investigation that included sampling of mine cut no. two was conducted by T.V.A. The results of this investigation appear in three reports: Rankin and Johnson (1936), Rankin (1936), and Rankin and Laurence (1936). Rankin and Johnson (1936) is essentially a lab report on samples from mine cut no. two, plus a short introduction. Rankin and Johnson (1936, p. 2) basically agree with the interpretation of Stose and Schrader (1923) regarding carbonate ore, and comment that the oxide ore was "derived by weathering of the underlying [dolostone]." They note that no rhodochrosite was seen, and that the carbonate rhombs probably contain little manganese, because when weathered and oxidized they remain white while the banded matrix becomes black. They conclude that "it is the banded material which must be considered the principal ore of the carbonate bodies," and comment on the existence of manganese oxides but not carbonate at the other dolostone outcrops (Rankin and Johnson, 1936, p. 2).

The report by Rankin (1936) summarizes the sample analyses of Rankin and Johnson (1936). A number of sketch maps are included in the report, one of which, reduced in size, is included herein (Figure 15) because it shows the sample locations, some of which were inaccessible to this writer due to extensive caving. The samples, except for sample number one, are continuous samples taken along five feet of vertical distance. Chemical analyses are reported in Table II below.

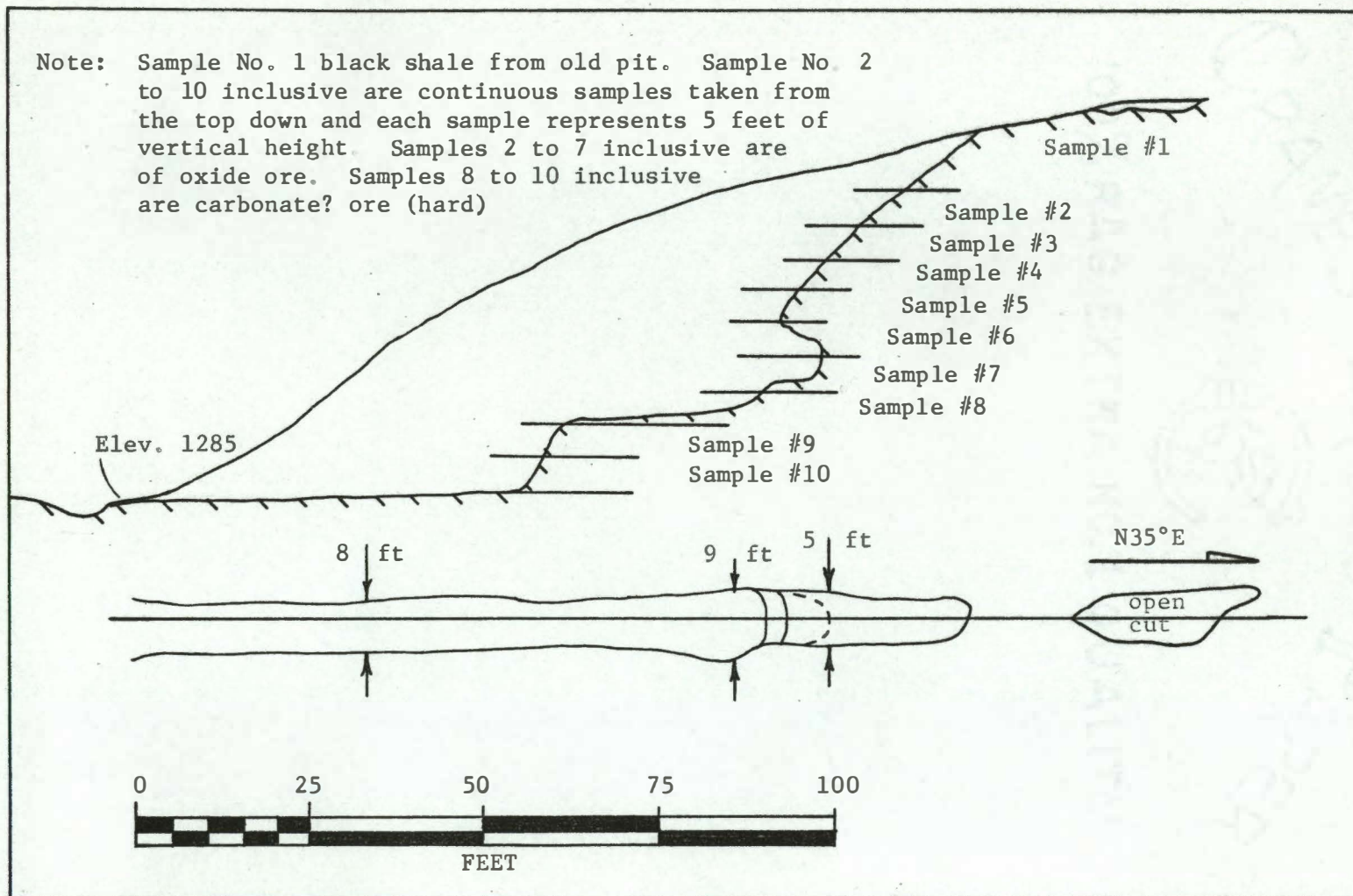


Figure 15. Sample locations in mine cut number two, East Fork.

Source: Rankin (1936, p. 4). Bar scale added by the writer.

TABLE II

CHEMICAL ANALYSES, MINE CUT NUMBER TWO, EAST FORK MINE

Sample	Percent Manganese	Percent SiO ₂	Percent CaO	Percent P ₂ O ₅
1	3.30			
2	21.85	15.54	6.56	1.58
3	9.56	11.60	7.04	
4	29.04	9.81	7.80	2.54
5	9.60	18.67	5.60	
6	8.58	13.37	6.00	
7	20.06	14.42	11.32	1.20
8	15.84	18.39	24.88	
9	20.06	20.40	15.88	
10	5.30			
*Average	15.54	15.27	10.63	1.77
*does not include sample no. 1				

Source: Rankin, 1936, p. 4.

Rankin (1936, p. 1) notes that "The ore varies abruptly from high to low manganese in content and with no way of determining the quality by appearance alone. . . ." The writer concurs with that observation, and indeed, the mine operator as well could not always estimate the quality of the ore on sight. Reichert (1942, p. 153) describes some sampling that he did under the direction of Mr. W. P. Martin, the mine operator. One sample said to be the best grade, estimated by Martin to contain 30% manganese actually ran only 9.61%. Another sample classed lower as "good grade carbonate ore" ran 27.98%, and another "good grade" ran only 7.76%. Reichert (1942, p. 153) ascribes the visual estimation difficulties to the absence of rhodochrosite. Presumably, the pinker the ore, the more rhodochrosite, and therefore the more manganese.

Rankin (1936, p. 1) believes that because of the ore grade identification problem, selective mining would not be practical, and therefore one could expect mine run ore to contain only about 17-18% manganese. If the ore bodies extended through the ridges along the outcrop, Rankin (1936, p. 1) calculates some 2,600,000 tons of "mineralized material" to be present. He concludes that, after considering the low ore grade, mining costs, and transportation to the rail head (at Sevierville), mining would not be practical.

Allowing for a 28.6% weight loss on ignition, as reported above in this chapter, the 17 to 18% mine run ore would be equivalent to 25-26% concentrate. Ferguson (1944, p. 1) reports that three carloads of concentrates (Table I, p. 42) were shipped in 1943 that averaged 28.76% manganese, a figure not far from the previous 25-25% calculated. But he also reports a carload (48 tons, estimated) of 43.32% concentrates and a 1942 shipment (one car) that ran 38% manganese. These averages are far higher than mine run average. These shipments may have represented oxide ore from mine cuts four, five, and six. In the reports described above, mention has been made that the oxide ore is higher in manganese content. Sample EF-15 from a dump at the mouth of mine cut no. 4 contains 34.74% manganese, and sample EF-7 from cut no. six contains 43.14% manganese, the highest of the 44 samples analyzed by the writer.

The conclusions in a report by Rankin and Laurence (1936) are essentially the same as in Rankin (1936); but the report also includes interesting commentary on ore genesis, plus the analyses for manganese of 26 samples taken along the dolostone outcrop. The authors regard the dolostone unit to be one of the limestone lenses mentioned by

Arthur Keith as characterizing the Hiwassee slate and comment that the presence of limestone conglomerate indicates shallow water depositional environment. The results of sampling the two miles of dolostone outcrop in the vicinity of the mine are summarized in Table III.

Rankin and Laurence (1936, p. 2) observe, as did earlier workers, that there were two types of manganese ore: oxides in residual clay, and carbonate in bedrock. They say that even with its low manganese content, the dolostone could serve as source material for the ore lenses. They say also that they are in agreement with Stose and Schrader (1923) in that the vertical restriction of the carbonate ore "indicates that they were formed by circulating ground waters just below the zone of oxidation, as suggested by Stose in his report." However, they also indicate that they are aware of problems in the explanation of Stose and Schrader (1923), noting that "It is difficult to explain why similar manganese deposits do not occur elsewhere along this [dolostone bed], or in similar [beds]." Perhaps they were

TABLE III

MANGANESE CONTENT OF DOLOSTONE SAMPLES, EAST FORK MINE VICINITY

Average Mn content of 26 samples	0.6%
Maximum Mn content in one sample	3.06%
Six samples contained over	1.50%
Average Mn content of 13 samples from lower part of [dolostone bed]	0.36%
Average Mn content of 5 samples from middle part of [dolostone bed]	0.95%
Average Mn content of 8 samples from upper part of [dolostone bed]	0.97%

Source: Rankin and Laurence (1936).

also wondering why the ore seems to occur only at or near the top of the dolostone bed. Regarding the localization of ore, Rankin and Laurence (1936, p. 4) conclude that

An excessive concentration of the original disseminated manganese carbonate, probably due to a local source of sedimentation, or favorable conditions for convergence of ground waters, due to shattering and local faulting near the mines, are the best explanations for the localization of the deposits.

It appears to the writer that Rankin and Laurence (1936, p. 4) were correct with the suggestion of a "local source of sedimentation." Also local fracturing has probably been a factor later in the history of East Fork.

A report by Butters (1940) discusses phosphorite occurrences and has further observations on the manganese ore. Butters (1940) does not specify which mine cut the report deals with, but the description seems to imply cut no. two. Butters (1940, p. 2) observes that "These manganese deposits may prove to be lenticular ones of small lateral extent." Also, he says that "In places along the cut, the ore body seems to jump from a higher to a lower bed, but at no place was the jump more than 6 inches or a foot." Butters (1940, p. 2) comments, in addition, on the numerous fractures and slickensides in the area, presumably the area of the mine cuts.

The observations of Ferguson (1944, p. 3) are particularly important because mining had resumed at East Fork and he was able to see fresh exposures. He too comments on slickensides evident in the slate on the southeast side of cut no. two. In cut no. three he reports ". . . blocks of [dolostone] separated by clay containing, in places, a high concentration of hard manganese oxides." At cut no. four he observed that "The southeast side is in clay and weathered

slate. . . ." Manganese and iron oxides were mined from clay at the slate-dolostone contact. Cut no. five must have been quite fresh at the time of his visit, having been opened in 1942-43, as reported above. Ferguson (1944, p. 3) reports that it is in slate and only one boulder of dolostone was exposed.

Taken together, the geological reports dealing with the manganese ore emphasize that the ore occurs at the slate-dolostone contact, i.e., at the stratigraphic top of the dolostone unit.

Phosphorite Occurrences

Phosphorite occurs about 400 feet northeast of manganese mine cut no. one, at TRC 2,772,750E, 533,000N, and also across Dunn Creek on a narrow ridge at TRC 2,773,400E, 533,200N. Butters (1940, p. 1) apparently visited both occurrences, and reports that the high grade material, which would be from the easternmost occurrence, runs 30 to 35% P_2O_5 . Gildersleeve (1942) toured the manganese mine cuts and made a closer inspection of the phosphorite outcrops, which had been recently blasted to improve the exposure. Gildersleeve (1942, p. 1) referring to the outcrop nearest mine cut no. one, mentions an outcrop and a new exposure ten feet above it, which may give some indication of the thickness of the phosphorite. On the other hand, these might also be two distinct, separate beds. At present only about two feet of phosphorite are exposed at a narrow bench. At the other occurrence nearby, phosphorite outcrop is not exposed, but a bulldozed trench contains much phosphorite float and several large boulders, and on the adjacent slopes, phosphorite float is abundant. When Gildersleeve (1942) examined this location, it had recently been blasted to create a fresh exposure.

He observed an 18 inch-thick bed within the larger exposure. Presumably he was referring to the phosphorite bed. Gildersleeve (1942, p. 2) concludes that these few exposures were not adequate for a proper evaluation of phosphorite potential.

The last investigation prior to that of the writer was that of Wedow, Carpenter, and Lehr (1966, p. 44). They interpret the outcrops as being part of an arkosic phosphorite bed 1,200 feet long and 4 feet thick. They report that the major phosphate mineral is francolite, $3\text{Ca}_3(\text{PO}_4)_2\text{CaCO}_3$, having cryptocrystalline texture and colloform structure. Mention is also made of the phosphorite occurrence in a road cut on Dixon Mountain, which was shown to the writer by Mr. Wedow.

The interpretation of Wedow, Carpenter, and Lehr (1966) also appears in Mineral Resources of the Appalachian Region, U.S. Geological Survey Professional Paper 580 (Wedow and Stansfield, 1968, p. 283-84).

Sometime after 1942 and many years before 1966, a bulldozer cut was made across the eastern exposure near Dunn Creek, diagonally to regional strike. This was evidently the last attempt at mineral development at East Fork.

CHAPTER V

CURRENT INVESTIGATIONS

Field Procedures

The map locations of samples, attitude measurements, outcrops, shapes of mine cuts, and cultural features were determined by tape and Brunton compass measurement. Samples were selected that would provide the most information about country rock and ore, with ore genesis being the prime consideration. The writer made no attempt at determining overall ore grade or at making a statistically representative sampling of the entire area. The T.V.A. reports cited above give a good indication of overall grade because they deal with bulk ore. Dolostone outcrop sampling, Table III, p.49, is covered as well. Therefore, visual inspection of the mine cuts and country rock determined what and where to sample. Oxide and carbonate ore samples were collected as well as country rock and a suite of phosphorite samples.

Manganese Ore - Gross Aspects

Spatial Relationships

The open mine cuts (Plate 4) are all near the stratigraphic top of the dolostone bed. Cuts two, three, and four straddle the dolostone-slate contact. Cuts no. one and six are almost entirely within the dolostone, and cut no. five is stratigraphically above the dolostone in slate. The stratigraphic relationship of the manganese ore being on or near the top of the dolostone bed, or on the south side, was probably evident to the prospector who dug the three small pits along the

dolostone outcrop shown on Plate 3. This stratigraphic positioning, the lenticular nature of the ore, and the non-uniform distribution of the ore indicates to the writer that the manganese was originally formed as pods contemporaneously with the dolostone. The carbonate ore and oxide ore spatial relationship is also of interest. The carbonate ore occurs at depth and the oxide ore (Figures 16 and 17) occurs above it. This implies, as noted in Stose and Schrader (1923) and in the T.V.A. reports cited above that the oxide ore is a weathered, residual product derived from decomposition of the carbonate ore. The only exception to the stratigraphic positioning of the ore being near the top of the dolostone is at cut no. one, where oxide ore extends stratigraphically deeper into the unit. But even there, judging from earlier reports, the tunnel at this cut (now caved) was driven along a carbonate lens, and the tunnel is near the stratigraphic top of the bed so that the general spatial relationship still holds. Oxide ore is more pervasive forming crumbly, earthy "shoots." As indicated earlier, the writer believes that the "shoots" may be a function of extensive fracturing of the otherwise competent dolostone. The dip of the dolostone bed is reversed at or near cut no. one, indicating that the bed was twisted and fractured during regional deformation.

Physical Characteristics

There are marked differences between the carbonate ore (Figures 18 and 19) and the oxide ore. The carbonate ore is dense and compact, and consists of dolomite rhombs set in a slightly calcareous dark matrix that has a banded structure (Figure 18) where rhombs are absent. The rhombs are uniformly in the 1 to 2 mm range, and euhedra predominate.



Figure 16. High grade oxide ore with boxwork of quartz veinlets. Sample is EF-7, 42% MnO, by XRF analysis.



Figure 17. Oxide ore with colloform structure. Sample is EF-31, 21% MnO, by XRF analysis.

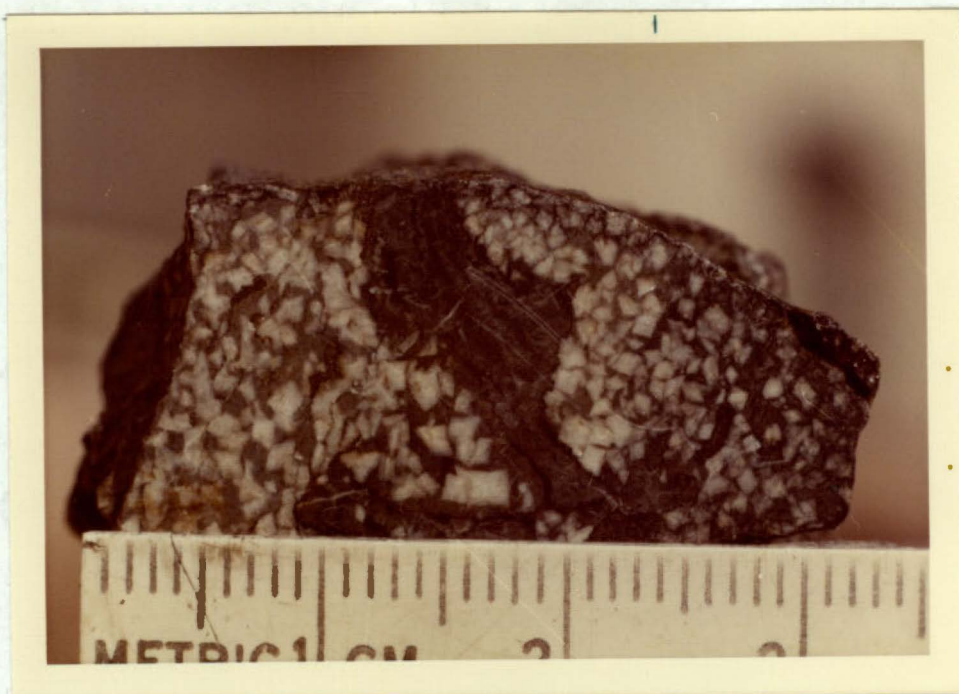


Figure 18. Sample EF-43, carbonate rhombs and black, banded matrix. Bulk analysis: 16% MnO, by XRF method.



Figure 19. Sample EF-38, carbonate rhombs. Bulk analysis: 8.2% MnO, by XRF method.

Oxide ore includes several types: massive material having colloform structure, material with a vuggy or scoria-like appearance, and earthy, punky material. All types range in color from dark yellowish brown (10YR4/2) to black (N1), and some high-grade massive ore has a blue-black color (Figure 16, p. 55). However, the writer verifies earlier reports that color is an unreliable indicator of ore grade at East Fork. Massive ore is stained in various shades of yellow, brown and red, from limonite and hematite after pyrite. Pyrite is very common in the ore, generally occurring as cubes in the 0.1 to 1.0 mm range. Massive ore is cut by numerous quartz veinlets. Most veinlets are less than 0.5 mm thick, but some range to 2 or 3 mm thick. It is common for veinlets to have a roughly parallel trend, probably due to siliceous fluids penetrating the ore along shear planes that resulted from regional deformation. Where the veinlets form an intersecting network (Figure 16, p. 55), weathering of the ore produces a protruding boxwork.

Colloform structure is evident in specimens where the buds range to 4 or 5 mm, as in Figure 17, p. 55. In other specimens, hand lens examination or binocular microscope observation reveals a microcolloform structure lining the vugs and open fractures, layer upon layer. The colloform surface typically consists of shiny black buds in the 0.5 to 1 mm range. Colloform structure is the dominant structure in the massive oxide ore.

Wall rock alteration consists principally of leaching and oxidation of manganiferous dolostone. It is particularly evident at the south wall of cut no. one, and in the thoroughly sheared dolostone and ore at the mine face under the overhangs in cuts one and three. On the

north wall at the mouth of cut no. two, the ore contains magnetite, possibly as an alteration product after pyrite. Magnetite is of sufficient concentration to attract a small magnet suspended from a string, but this is a local, very limited occurrence.

Phosphorite Prospects

Two phosphorite prospects are shown on Plate 5. The eastern prospect is a trench cut in sandstone, and the western prospect is an exposure at a shallow, man-made bench, also cut in sandstone. Sandstone at the western exposure is very thinly bedded (Figures 20 and 21) and overturned steeply to the northwest. The base of the laminated phosphorite cannot be seen directly, but the face of the bench cuts diagonally across the phosphorite and no further indications are seen. The phosphorite is very-thinly laminated and the main constituent is fine-grained quartz sand. A few rounded to subangular quartz grains occur that reach 2 mm in diameter. The phosphorite contains scarce grains of feldspar, seen mainly as angular to rounded bodies of soft, white alteration product to 2 mm in diameter. A few grains of more competent white feldspar are also present. Bulk analysis of sample EF-24, shown in Figure 20, yields 3.2% P_2O_5 , which probably occurs mainly in the thin dark laminations (Figure 21). The phosphorite is cut by several quartz veinlets up to 1 mm thick. The diapir-like white vein cutting through laminae in Figure 21 is a 0.25 mm quartz veinlet offset 1 mm to the left, along the dark lamina. The offset portion is just out of the field of view. The offset is probably due to shearing that occurred during regional deformation. Sample EF-23 apparently overlies EF-24 by a distance of 5 feet. XRF analysis shows



Figure 20. Sample EF-24, bedded phosphorite. Black square shows the area of the photomicrograph in Figure 21.

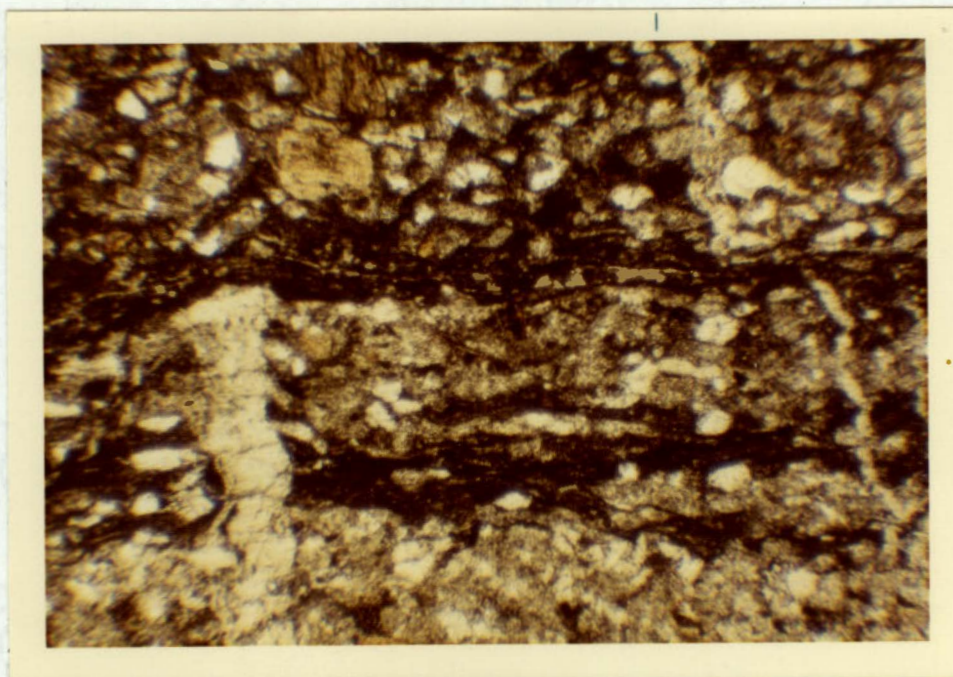


Figure 21. Photomicrograph of laminations in phosphorite. Diameter of field of view, 3.6 mm.

that EF-23 contains 28.9% P_2O_5 . This particular phosphorite is massive, not laminated, as shown in Figure 22. Its color is medium bluish gray (5B5/1) and it is very hard and brittle, breaking into sharp-edged pieces. Bulk composition is 65% bluish gray matrix, 5% quartz veinlets, 10% quartz grains, and 20% white feldspar as cleaved grains and softer weathered masses, from 0.5 to 3 mm in diameter. Quartz grains are angular to round. Within the black square indicated in Figure 22, a 2 mm quartz grain occurs entirely within a weathered but still competent mass of feldspar, probably indicating secondary rather than clastic feldspar.

The western phosphorite overlies the dolostone bed. The thickness of the sediments between the top of the dolostone and the closest verified phosphorite outcrop is 94 feet, assuming a uniform dip of 70° to the northwest. However, there may be another phosphorite bed 10 feet closer to the dolostone as reported by Gildersleeve (1942, p. 51). The general geological setting, then, appears to be 5 feet of phosphorite separated from the dolostone by 94 feet of sandstone, with possibly another phosphorite bed occurring 10 feet below the laminated phosphorite.

At the eastern prospect, phosphorite in place was not seen. Debris around the trench indicated a medium to coarse-grained sandstone host rock overlain by silty sandstone. Phosphorite float is abundant, and it is coarser grained than phosphorite at the western prospect. Samples EF-1 and EF-2 from this site are virtually identical to EF-23 described above. They, too, are massive and very well indurated, and have the same general composition as EF-23. Sample EF-4 (Figures 23 and 24) consists entirely of rounded quartz grains to 4 mm in diameter and rounded pebbles of gray phosphorite. Quartz grains have etched

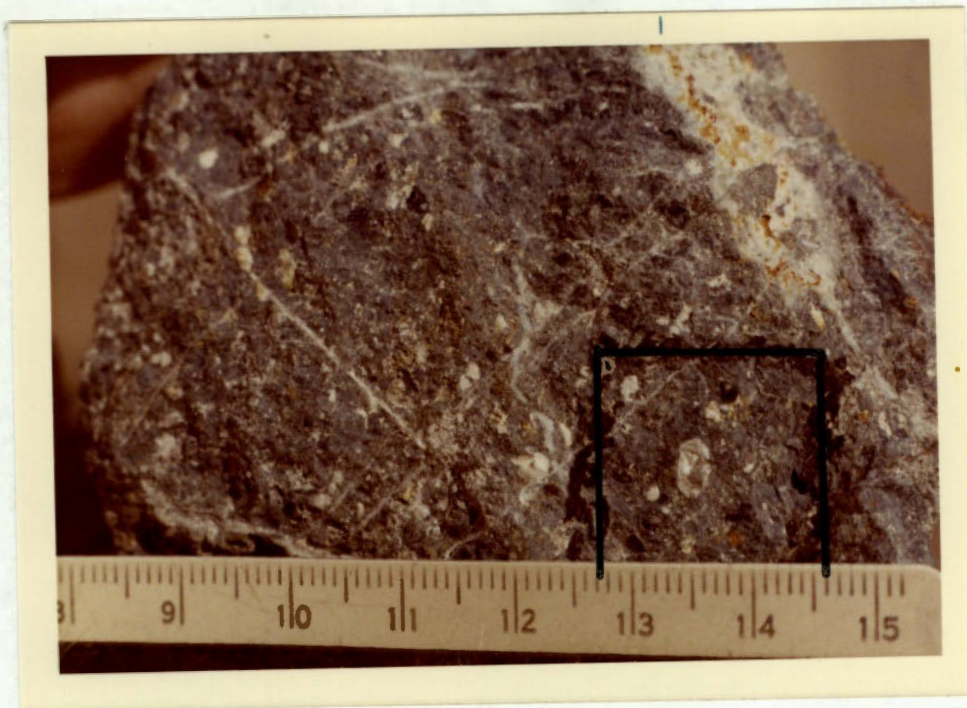


Figure 22. High grade, massive phosphorite, sample EF-23. Contains 28.9% P_2O_5 , by XRF analysis.



Figure 23. Sample EF-4, coarse grained phosphorite. Both quartz and phosphorite pebbles can be seen.

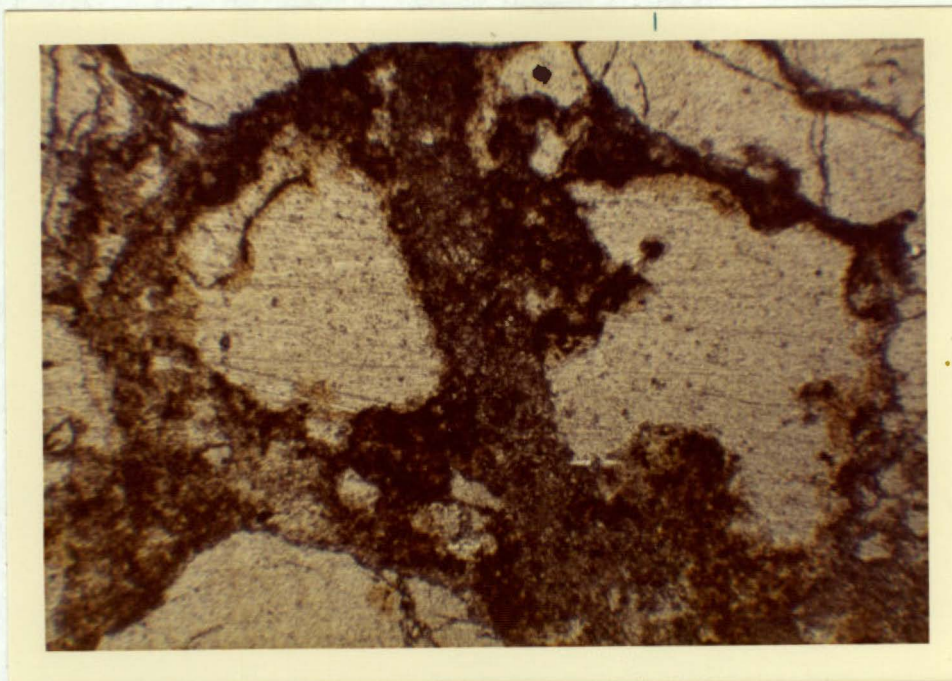


Figure 24. Photomicrograph of EF-4. Shows dark matrix of phosphorite, and fractured etched quartz grains. Field of view is 3.6 mm wide.

embayments filled with phosphorite matrix, and many grains have a fractured, shattered appearance.

Similar to the western outcrop, this phosphorite also overlies the dolostone bed. The writer estimates 330 feet of sediment stratigraphically between the dolostone and this phosphorite, but only 140 feet between the phosphorite and the nearest stratigraphic horizon in which limestone occurs.

The phosphorite on Dixon Mountain, mentioned earlier in this report and represented by sample 46, is similar to the eastern deposit. That is, both massive and pebbly phosphorite occurs, and each phase has characteristics similar to its complement at the eastern prospect. Quartz grains in the pebbly phase are more angular, more abundant, and somewhat more fractured than those of sample EF-4.

Laboratory Procedure for Manganese and Phosphorus Analyses

General

Forty-four samples were analyzed by X-ray fluorescence (XRF) methods for manganese and phosphorus. Representative chips, totalling approximately 12 to 14 grams in each case were taken from each of the 44 hand specimens. The chips from a given sample were ground entirely to minus 200 mesh in a small oscillatory ball mill using tungsten balls in a steel cannister. The product was then transferred to air tight 20 ml plastic bottles, the mill and sieve cleaned, and the process repeated on the next sample. Three of the ground samples were selected to serve as a basis for standards and were analyzed for MnO and P_2O_5 by a commercial laboratory using wet chemical methods. These three "knowns" (EF-15, EF-10, and JB-94) were then blended with each other in varying proportions to furnish 10 standards (Table IV). Each standard contains 1.0 g of rock material plus 0.1 g of methyl cellulose which acts as an inert binder. The 10 standards were intended to cover the estimated range of manganese and phosphorus content in the remaining samples. The selection of the three "knowns" was based on visual inspection of hand specimens and a preliminary XRF comparison. Subsequent XRF analyses revealed several samples that were higher than the standards. In such cases the sample was diluted by one-half in order to bring its analysis within the range of the standards. The resulting MnO or P_2O_5 determination was then doubled to bring it back up to the true level of the undiluted sample.

To establish a lower limit for the standards, a blank pellet was prepared that consisted only of methyl cellulose. Using this pellet,

TABLE IV

X-RAY FLUORESCENCE STANDARDS

Standard	Milligrams of EF-15	Milligrams of EF-10	Milligrams of JB-94	Weight % MnO	Weight % P ₂ O ₅
EF-15	1000.0	0	0	34.74	0.17
EF-10	0	1000.0	0	1.09	0.20
JB-94	0	0	1000.0	0.03	20.50
A	850.0	0	150.0	29.54	3.22
B	700.0	0	300.0	24.33	6.27
C	600.0	0	400.0	20.86	8.30
D	500.0	500.0	0	17.92	0.19
E	350.0	600.0	50.0	12.81	1.02
F	170.0	130.0	700.0	6.07	14.41
G	0	500.0	500.0	0.56	10.35

the writer could determine what level of XRF count was associated with a known zero weight percent of manganese or phosphorus.

The Siemens XRF system employed in this study analyzes pelletized material. Standards and samples were pelletized as follows: One gram of ground product (minus 200 mesh) was blended with 0.1 gram of methyl cellulose which acted as a binder. The mixture was dumped into a polished mold, covered with additional methyl cellulose, and compressed under 20 tons ram pressure (approximately 20 tons per square inch). The result is a firm pellet 31 mm in diameter and four to five millimeters thick, with the material to be analyzed forming one extremely smooth face 27 mm across, exactly matching the aperture of the pellet holder in the XRF unit. Pellets have the advantage, if they are kept in a desiccant, of being physically durable and chemically fixed, making them convenient to handle and also enhancing the repeatability of analyses. If not stored in a desiccant, the smooth surface will absorb moisture from the atmosphere, dome-up, crack and spall off.

The XRF system employed consists of three units: a power console, an X-ray fluorescence unit, and an information display console that contains a cathode-ray tube display, an intensity meter, a glowing filament-type digital display, and printed tape. Variables in the system are voltage and amperage of the X-ray power source, composition of the X-ray target, composition of the diffracting crystal, diffraction angle (i.e. the two-theta angle), length of count, number of count repetitions, and the aperture of the pellet holder (7 or 27 mm).

The intensity of X-ray fluorescence per unit of time, i.e., counts per second, is proportional to the amount of fluorescing material in the sample. The cathode ray tube and intensity meter give a visual display of intensity, and the intensity meter also indicates whether or not the fluorescence detector is approaching saturation or is unacceptably low, either case calling for a power adjustment or aperture change. The glowing filament tubes and printed tape display the XRF count numerically. The count cycle was controlled by an automatic timer set for 5 repetitions each of 0.4 minutes duration. All samples were counted in this manner, with the final reported count being the arithmetic mean of the 5 counts. Analysis of all 44 samples plus the standards required three hours. To check for "drift" in the counting system, a given standard was re-run at selected intervals and the count compared to the original. If drift was encountered, a cumulative drift curve was plotted and the sample count corrected according to its location along the drift curve. Drift was assumed to be time constant. Thus, samples run later in the procedure would get a larger correction factor. No drift was encountered in the manganese detection procedure,

which uses an LiF crystal, but drift was encountered in the phosphorus procedure, which uses a P.E.T. crystal that is somewhat heat sensitive.

Preliminary scanning of the samples permitted separating them into four categories according to weight percent of MnO or P_2O_5 . The categories or groups, were: high MnO, low MnO, high P_2O_5 , and low P_2O_5 .

Manganese Determinations

The manganese samples were all run under the following conditions: gold X-ray target, power at 37 KV and 4mAmp, and LiF diffraction crystal set at 2θ of 62.97° . The samples high in MnO were placed in a holder with a small (7 mm) aperture, and those low in MnO were run using a large aperture. The relationship between XRF count and weight percent MnO in the standards is diagrammed in Figures 25 and 26. A least-squares regression line is plotted in order to determine the MnO content of the unknowns from their respective XRF counts. The lower theoretical limit of usable XRF counts for MnO with this set of standards is approximately 34, the Y-intercept of the least square regression line (Figure 26) from which weight percentages are estimated for the samples low in MnO. That is, given a count of 34, weight percent of MnO is zero, according to the regression line. But, the blank pellet yields a count of 17. Standard JB-94, 0.03% MnO, yields a count of 18, almost the same as the blank pellet. Obviously at extreme low counts the results are not valid. Consistent results were obtained with counts down to a level of 50, corresponding to 0.05% MnO and so this level was accepted as the lower threshold for the manganese determinations.

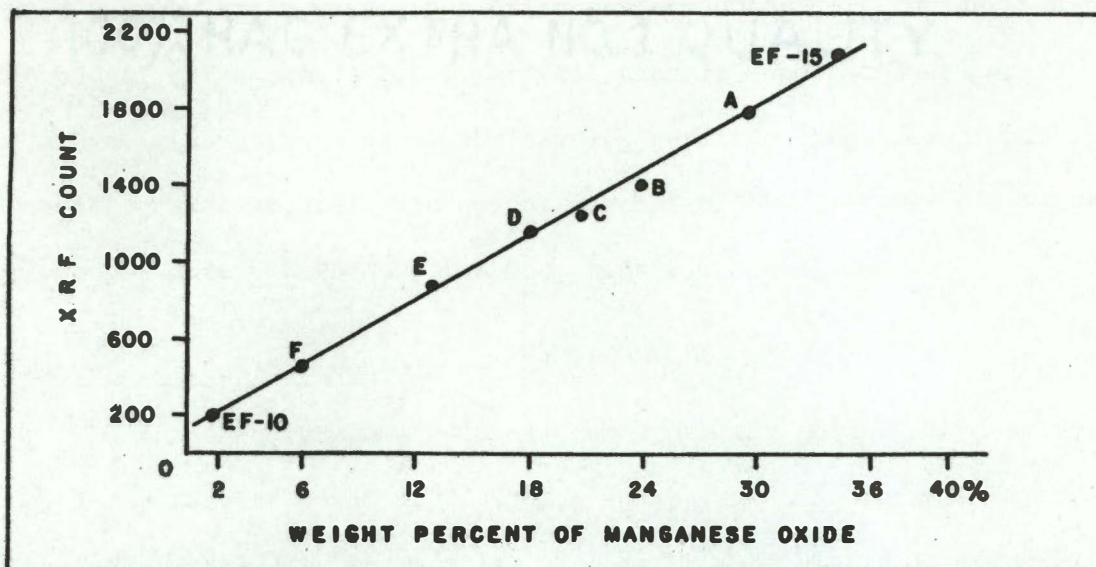


Figure 25. High-manganese standards.

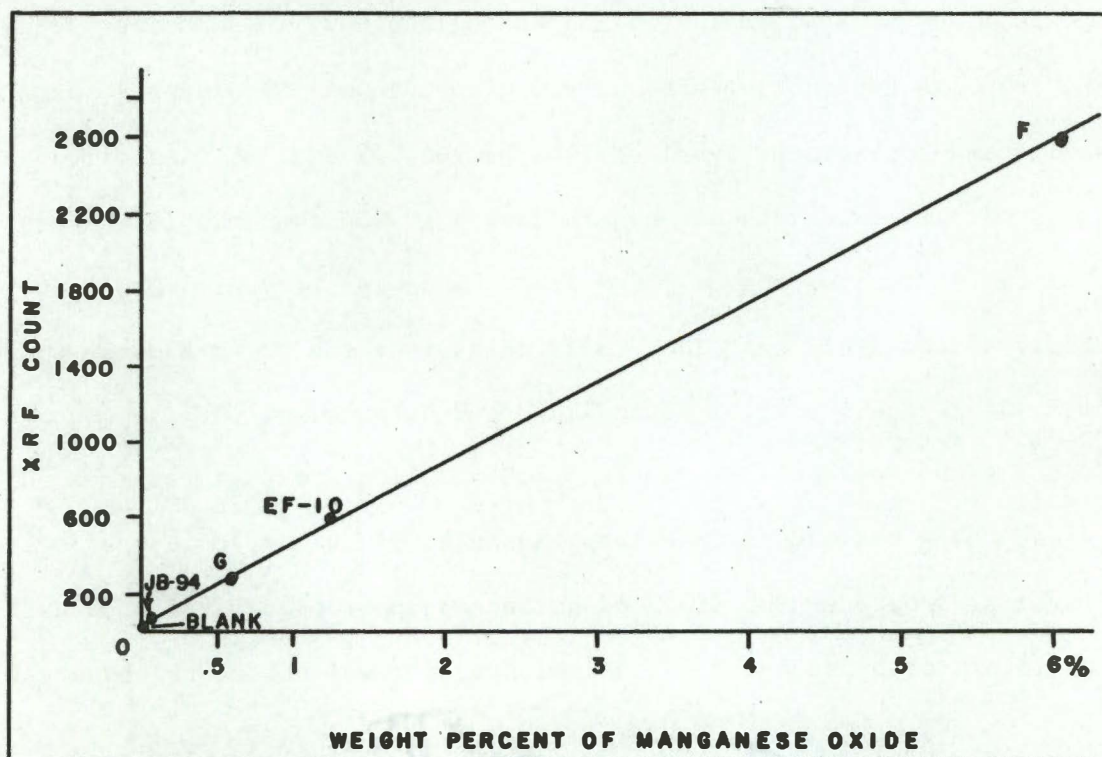


Figure 26. Low-manganese standards.

Phosphorus Determinations

Both the high and low P_2O_5 groups were run with a chromium X-ray target, P.E.T. diffraction crystal set at 2θ of 89.40° , and large aperture pellet holder. The two groups of samples required different power settings for optimum results. The group of samples high in P_2O_5 were run at 37 KV and 17mAmps, and the low group at 48 KV and 47mAmps. Count cycle was unchanged. Figures 27 and 28 show the relationship between XRF count and P_2O_5 content of the standards. A least squares regression line was plotted in order to determine the P_2O_5 content of the unknowns from their respective XRF counts.

Results of XRF Analyses

Because the sample groups were analyzed under different conditions, they are tabulated separately. Listing is in numerical order by sample number within each group. Table V lists the samples with a high manganese content. This group ranges from 43.14% MnO to 1.10% MnO. Where a sample is listed twice, as with EF-7 and EF-31, the listing with an associated XRF count is that of a sample diluted by one-half, and the true value is listed directly above the diluted value. The notation "Mn Ore" means manganese oxide ore, except in the case of samples EF-38, 40, and 43, which are carbonate ore samples. Sample locations are shown on Plates 1, 3, 4 and 5 (map pocket).

Low-manganese group analyses are presented in Table VI. The notation "-0.05" indicates that the count is below the reliable threshold, and therefore the only thing certain is that there is less than 0.05% MnO present.

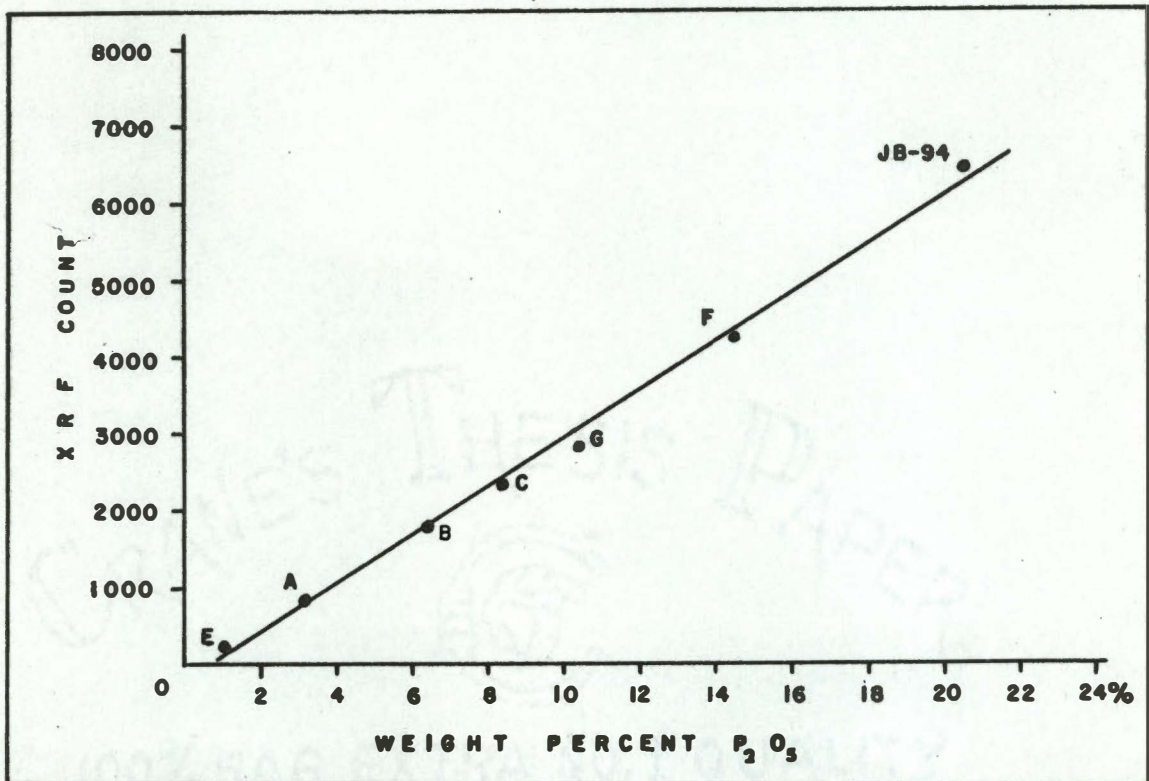


Figure 27. High-phosphorus standards.

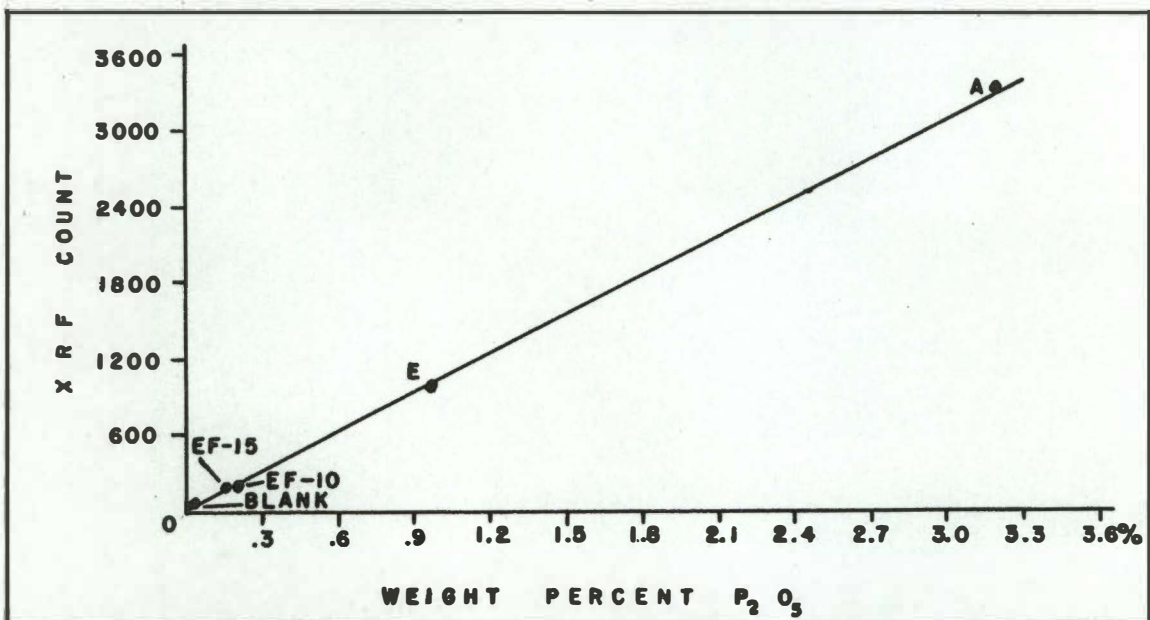


Figure 28. Low-phosphorus standards.

TABLE V

EAST FORK SAMPLES WITH HIGH-MANGANESE CONTENT

Sample	Material	Count	Weight Percent MnO	Sample	Material	Count	Weight Percent MnO
EF-7	Mn Ore		43.14	EF-31	Mn Ore		42.92
EF-7		1346	21.57	EF-31		1340	21.46
EF-10	Siltstone	212	1.10	EF-32	M-quartzite	416	4.79
EF-12	Oxide residue	587	7.87	EF-33	Limestone	306	2.80
EF-13	Mn Ore	271	2.17	EF-34	Dolostone	382	4.17
EF-15	Mn Ore	2130	34.74	EF-38	Mn Ore	606	8.21
EF-20	Mn Ore	1938	32.26	EF-40	Mn Ore	1407	22.69
EF-28	Dolostone	292	2.55	EF-43	Mn Ore	1059	16.39
EF-30	Siltstone	636	8.77	EF-44	Mn Ore	1340	21.46
				Blank		150	0.00

TABLE VI

EAST FORK SAMPLES WITH LOW-MANGANESE CONTENT

Sample	Material	Count	Weight Percent MnO	Sample	Material	Count	Weight Percent MnO
EF-1	Phosphorite	11	-0.05	EF-37	Siltstone	175	0.33
EF-2	Phosphorite	12	-0.05	JB-27	Sandstone	26	-0.05
EF-4	Phosphorite	9	-0.05	JB-33	Sandstone	254	0.51
EF-5	Siltstone	1038	2.34	JB-46	Phosphorite	26	-0.05
EF-9	Siltstone	204	0.40	JB-55	Dolostone	44	-0.05
EF-17A	Dolostone	795	1.77	JB-82	Dolostone	57	0.05
EF-22	Dolostone	865	1.94	JB-84	Dolostone	470	1.02
EF-23	Phosphorite	12	-0.05	JB-88	Siltstone	707	1.57
EF-24	Phosphorite	16	-0.05	JB-89	Dolostone	443	0.95
EF-25	Graywacke	16	-0.05	JB-94	Phosphorite	18	0.03
EF-26	Dolostone	116	0.19	JB-95	Dolostone	55	0.05
EF-27	Pyritic Qtz.	38	-0.05	JB-96	Dolostone	73	0.09
EF-35	Dolostone	649	1.43	JB-97	Dolostone	36	-0.05
EF-36	Siltstone	37	-0.05	Blank		17	0.00
EF-36A	Gossan	534	1.16				

Phosphorus analysis results are grouped together for the reasons cited for the manganese groupings. Table VII lists the high-phosphorus samples. Highest value recorded is sample EF-23, with 28.94% P_2O_5 . As with the manganese listings, two values listed for the same sample number indicate that dilution was necessary, and the highest value is the actual P_2O_5 content.

Analyses of the group low in P_2O_5 are recorded in Table VIII. Analyses range as low as 0.11% P_2O_5 .

In order to make a more convenient comparison between MnO and P_2O_5 values, the data are all combined in Table IX, listed in descending order of MnO value. For visual comparison, the same data are plotted as a histogram, Figure 29.

In order to determine the phosphorite mineralogy, the writer tested several pellets by means of X-ray diffraction. Records tend to be complicated with quartz and clay peaks, but sample EF-23 yielded a fairly clean record, indicating the presence of calcium fluorapatite, $Ca_5(PO_4)_3F$.

Microprobe Procedure

Three thin sections (JB-89, EF-37, and EF-43) were polished on a diamond lap and then coated with approximately 20Å of carbon to prepare them for mounting in an A.R.L. electron microprobe. This unit has two fixed channels (i.e. detectors). For the purposes of this report the channels were calibrated for iron and manganese using factory-prepared standards of known composition. The main objective in using the microprobe was to determine whether or not certain portions of the polished sections were high in manganese compared to other portions. At the same

TABLE VII

EAST FORK SAMPLES WITH HIGH P_2O_5 CONTENT

Sample	Material	XRF Count	Weight Percent P_2O_5	Sample	Material	XRF Count	Weight Percent P_2O_5
EF-1			27.52	EF-24	Phosphorite		3.24
EF-1	Phosphorite	4157	13.76	EF-25	Graywacke	323	1.50
EF-2			22.18	JB-46	Phosphorite	2118	7.24
EF-2	Phosphorite	3324	11.09	JB-84	Dolostone	183	1.05
EF-4			21.70	JB-94	Phosphorite	6547	20.50
EF-4	Phosphorite	3246	10.85	Blank		10	0.0
EF-23			28.94				
EF-23	Phosphorite	4377	14.47				

TABLE VIII

EAST FORK SAMPLES WITH LOW- P_2O_5 CONTENT

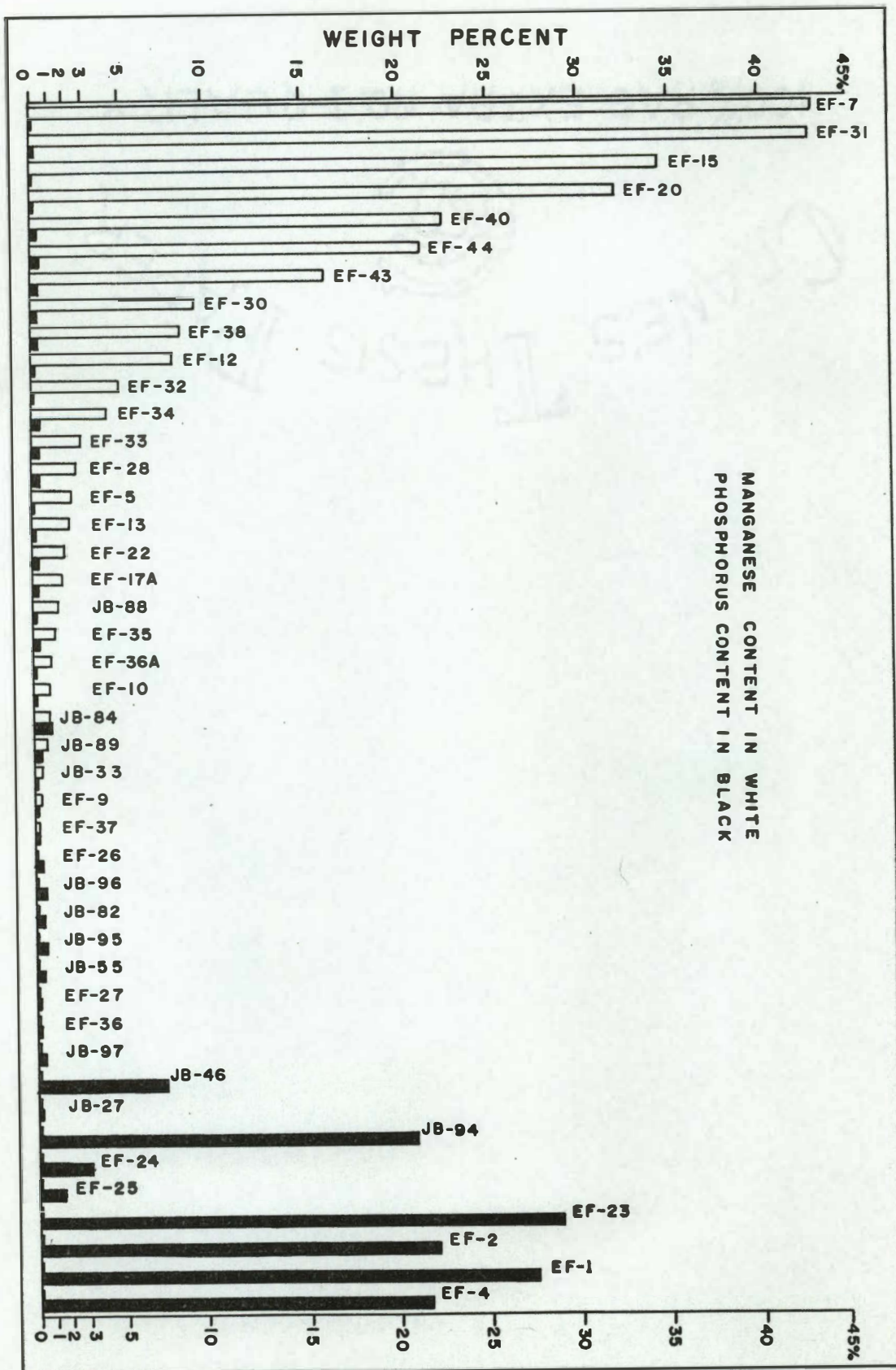
Sample	Material	XRF Count	Weight Percent P_2O_5	Sample	Material	XRF Count	Weight Percent P_2O_5
EF-5	Siltstone	77	0.09	EF-36	Siltstone	244	0.23
EF-7	Mn Ore	133	0.14	EF-36A	Gossan	214	0.22
EF-9	Siltstone	237	0.24	EF-37	Siltstone	332	0.33
EF-12	Oxide residue	262	0.27	EF-38	Mn Ore	374	0.38
EF-13	Mn Ore	214	0.22	EF-40	Mn Ore	332	0.33
EF-17A	Dolostone	412	0.41	EF-43	Mn Ore	427	0.42
EF-20	Mn Ore	233	0.24	EF-44	Mn Ore	417	0.41
EF-22	Dolostone	440	0.44	JB-27	Sandstone	99	0.11
EF-26	Dolostone	523	0.52	JB-33	Sandstone	207	0.21
EF-27	Pyritic Qtz.	101	0.11	JB-55	Dolostone	391	0.39
EF-28	Dolostone	482	0.48	JB-82	Dolostone	538	0.53
EF-30	Siltstone	326	0.33	JB-88	Siltstone	283	0.29
EF-31	Mn Ore	312	0.31	JB-89	Dolostone	518	0.51
EF-32	Metaquartzite	176	0.18	JB-95	Dolostone	626	0.62
EF-33	Limestone	444	0.44	JB-96	Dolostone	653	0.64
EF-34	Dolostone	504	0.50	JB-97	Dolostone	503	0.50
EF-35	Dolostone	541	0.53	Blank		33	0.00

TABLE IX

MANGANESE AND PHOSPHORUS CONTENT OF EAST FORK SAMPLES

Sample	Weight Percent MnO	Weight Percent P ₂ O ₅	Sample	Weight Percent MnO	Weight Percent P ₂ O ₅
EF-7	43.14	0.14	JB-84	1.02	1.05
EF-31	42.92	0.31	JB-89	0.95	0.51
EF-15	34.74	0.17	JB-33	0.51	0.21
EF-20	32.26	0.24	EF-9	0.40	0.24
EF-40	22.69	0.33	EF-37	0.33	0.33
EF-44	21.26	0.41	EF-26	0.19	0.52
EF-43	16.39	0.42	JB-96	0.09	0.64
EF-30	8.77	0.33	JB-82	0.05	0.53
EF-38	8.21	0.38	JB-95	0.05	0.62
EF-12	7.87	0.27	JB-55	-0.05	0.39
EF-32	4.79	0.18	EF-27	-0.05	0.11
EF-34	4.17	0.50	EF-36	-0.05	0.23
EF-33	2.80	0.44	JB-97	-0.05	0.50
EF-28	2.55	0.48	JB-46	-0.05	7.24
EF-5	2.34	0.09	JB-27	-0.05	0.11
EF-13	2.17	0.22	JB-94	-0.05	20.50
EF-22	1.94	0.44	EF-24	-0.05	3.20
EF-17A	1.77	0.41	EF-25	-0.05	1.50
JB-88	1.57	0.29	EF-23	-0.05	28.94
EF-35	1.43	0.53	EF-2	-0.05	22.18
EF-36A	1.16	0.22	EF-1	-0.05	27.52
EF-10	1.10	0.20	EF-4	-0.05	21.70

Figure 29. Manganese and Phosphorus Relationship.



time it was possible to obtain a semiquantitative analysis of the manganese and iron content of the area being scanned, as described below. Although the semiquantitative analysis is not as accurate as the XRF analysis, it provides useful data.

The microprobe output consists of a digital counter, and a scaled chart calibrated in counts per minute. Photographs of these charts are presented later in this report. In each case, the red traces (original copy) represent iron content, and the blue (original copy) represent manganese. Manganese content can be estimated fairly accurately by observing the number of counts registered on the digital counter per unit of time while X-raying the manganese standard, and proportioning to this the counts observed while scanning the unknown sample. For example, 100% manganese yielded a count of 120,000 when scanned for 10 seconds. If a sample were to yield a count of 3,000 when scanned for 10 seconds, it would thus contain approximately 2.5% manganese. Iron is estimated in a similar manner. The width of the microprobe chart limits visual estimates, i.e., estimates made by comparing the heights of peaks, to about 4% iron or manganese. "Spikes" greater than about 4% are estimated as described above, by observing the digital counter during scanning. An important feature of the microprobe is that the operator sees a magnified image of the object being scanned. Similar to operating a petrographic microscope, the operator views the object under crosshairs which in this case mark the impact point of the electron beam. The polished section can be moved about under the crosshairs to orient it or to analyze a particular point. Also it can be scanned automatically in a straight line at a given rate. The latter procedure

was employed in this report in order to more easily compare the charts of all three polished sections.

Microprobe Results

The microprobe was used to investigate the possibility of manganese in the cores of carbonate rhombs, as reported in Stose and Schrader (1923). It was also used to investigate the anastomosing purplish veinlets in a siltstone specimen collected at a trench between the two largest manganese mine cuts. The purplish color is suggestive of phosphorite.

Polished section EF-38 was cut from hand specimen EF-38 that contains 8.2% Mn and exhibits densely-packed well-developed rhombs (Figure 19, p. 56). The rhomb selected for analysis has a pinkish hue suggestive of rhodochrosite and is similar in color, size and location to the grain circled in Figure 19, p. 56. The path of the electron beam is marked by a line of black ink in Figure 30. The direction of movement is from right to left. The microprobe record, Figure 31, reads from right to left. The trace begins in black matrix material which runs quite high in manganese relative to the crystal. The record is irregular but a general background of about 1% manganese is indicated, particularly where unfractured, unpitted material is analyzed. In observing the grain moving under the crosshairs, the writer noted that whenever a fracture or pit was encountered, the iron and manganese analyses increased markedly, visible as "spikes" on the record. Spot checks on other grains showed a similar low level in their cores. It is apparent, then, that the 8.2% manganese present in this sample does not come from the core of the crystal, but rather from the

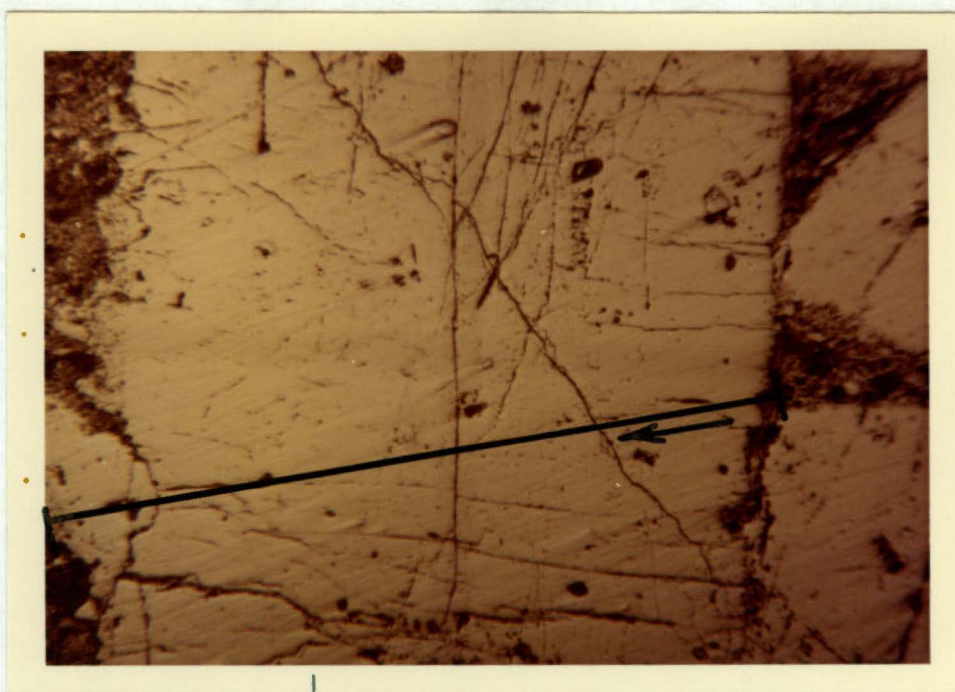


Figure 30. Photomicrograph of carbonate rhomb. Black line indicates path of electron beam. Field of view is approximately 1.5 mm in diameter.

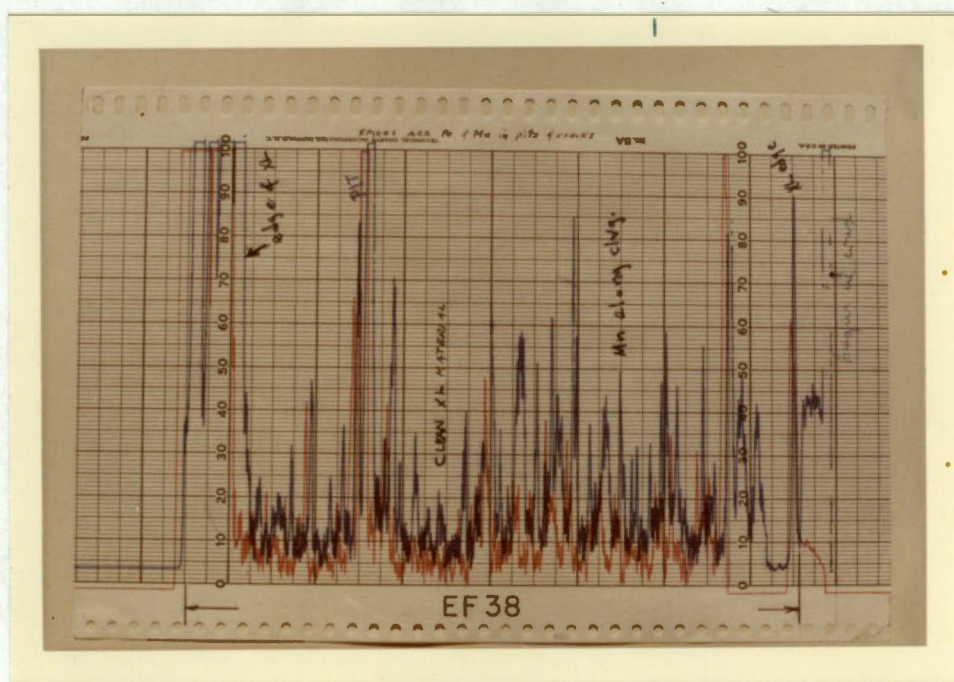


Figure 31. Microprobe record of scanning of sample EF-38. Blue trace indicates manganese, red trace indicates iron.

matrix material and from manganese that has entered the grain along fractures and cleavage planes.

Polished section JB-89 (Figure 32) was selected for analysis because it contains a zoned mineral grain, the zoning being marked by black bands. This polished section is cut from a dolostone specimen taken from the top of the ridge between mine cuts no. 2 and no. 3 (Plate 4). Although the specimen does not come from one of the mine cuts, as did the samples of Stose and Schrader (1923), it is the only zoned rhomb observed by the writer. It occurs in a veinlet; the remainder of the specimen is massive to poorly crystalline dolostone.

The path of the electron beam runs first in a black band parallel to the sides of the band and then turns abruptly into the core of the rhomb. The microprobe record, Figure 33, reads from right to left. Analysis shows that the black bands contain 15% to 20% iron and approximately 1.4% manganese. The core of the crystal contains approximately 1% manganese and 1.5% to 2% iron. Analysis by X-ray fluorescence (Table VI, p. 70) shows an 0.95% manganese content overall, indicating that the crystal is representative of the bulk composition of the sample with regard to manganese. The zoning in the crystal is due to iron, not to manganese.

Polished section EF-37 (Figure 34) was scanned across numerous dark bands that give a purplish hue to the hand specimen under normal lighting conditions. Scanning started in a silty pod and ended in a black area. The specimen runs consistently about 1/3% manganese and 3% iron overall, as indicated by the microprobe record, Figure 35. Black bands (Figure 34) contain about 5% to 6% iron. In observing the scanning, the writer noted that iron content increased markedly, forming

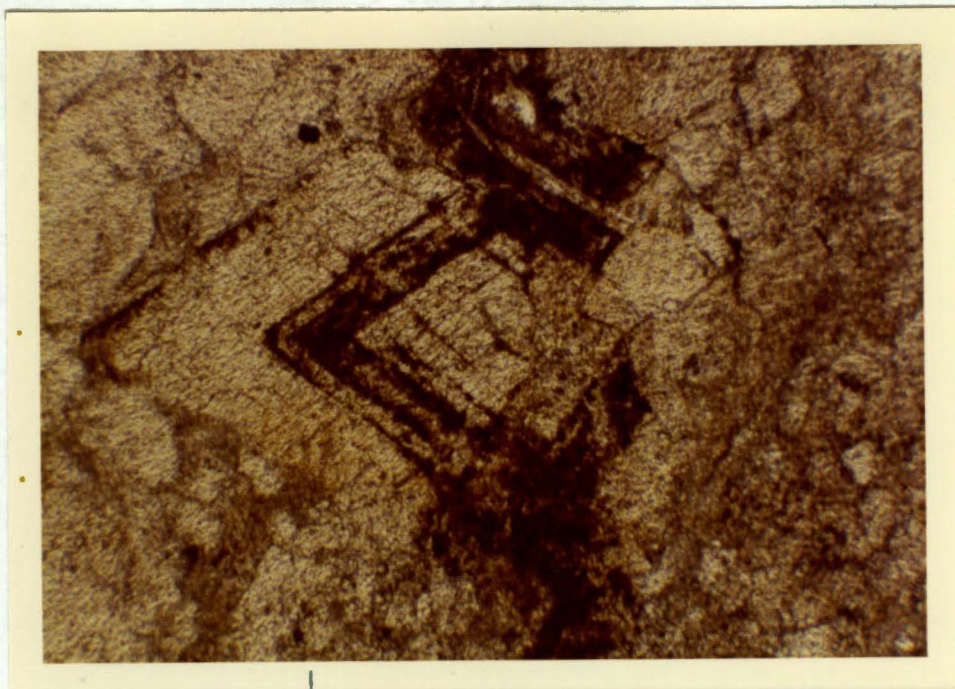


Figure 32. Photomicrograph of zoned rhomb. Field of view is 3.6 mm in diameter. Electron beam path is shown in black.

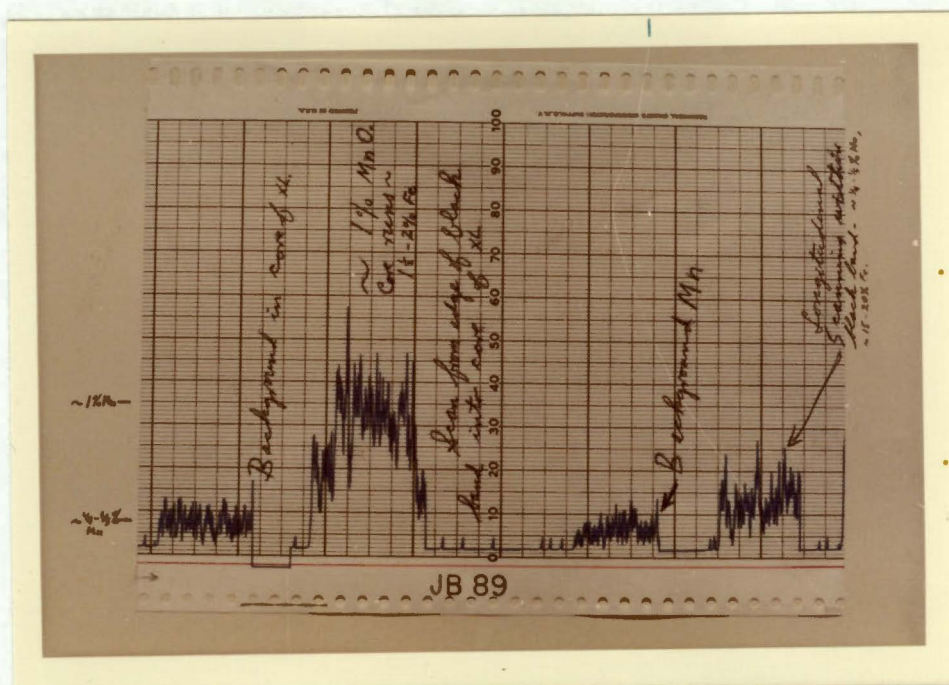


Figure 33. Microprobe record of scanning of zoned rhomb. Blue trace indicates manganese.

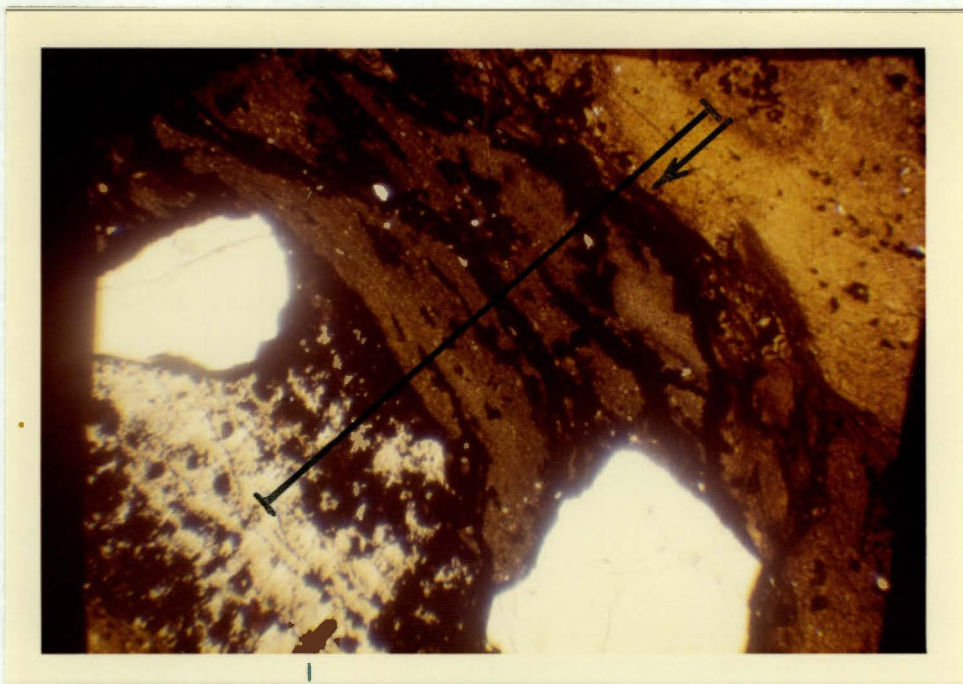


Figure 34. Photomicrograph of banding in sample EF-37. Field of view is 3.6 mm in diameter. Black line indicates path of electron beam.

"spikes" on the record whenever a black band was crossed. Analysis of the sample by X-ray fluorescence shows 0.33% manganese and 0.33% P_2O_5 . These results indicate that the purplish coloration is due to iron banding and not to phosphorite.

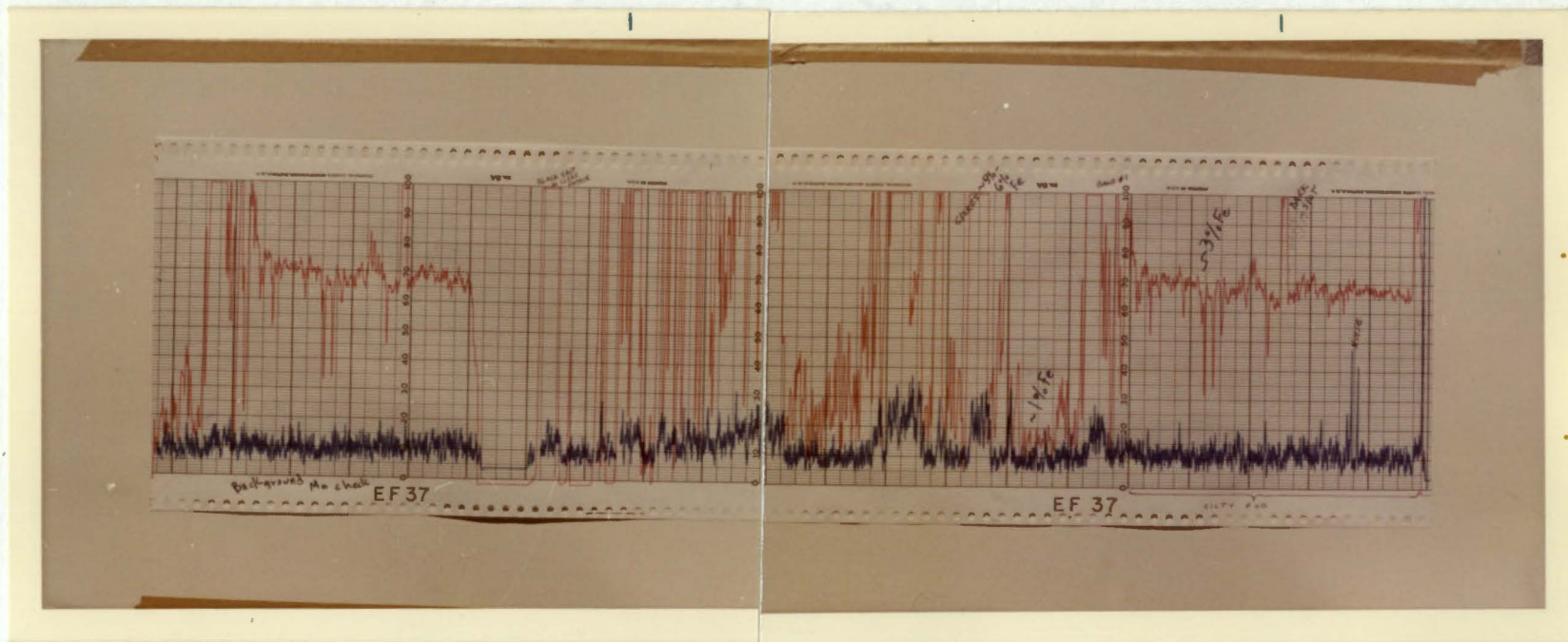


Figure 35. Microprobe record of scanning of sample EF-37. Blue trace indicates manganese, red trace indicates iron. Record reads from right to left.

CHAPTER VI

INTERPRETATION OF ANALYTICAL WORK AND FIELD MAPPING

Manganese and Phosphorus in Rocks

It is common knowledge that manganese deposits have been produced elsewhere by the weathering of igneous and sedimentary rocks, especially carbonate rocks. The writer feels that enough analyses have been made of the dolostone bed at East Fork to justify a valid comparison between it and rocks elsewhere. The writer finds that it is difficult to obtain data on what would be called an "average" dolostone, if indeed one exists. Therefore, several sources are cited in order to gain some idea of published levels of MnO and P₂O₅ in common rocks. The references used, summarized below in Table X, are: El Wakeel and Riley (1961, p. 123), Parker (1967, p. D9-11), and Wedepohl (1960, p. 260-61). In addition, data from Table III, p. 49, and Table IX, p. 73 are cited.

TABLE X

MANGANESE AND PHOSPHORUS CONTENT OF COMMON ROCKS AND EAST FORK DOLOSTONE

Source	MnO	P ₂ O ₅
Parker (1967) Mafic rocks	0.2	0.3
Silicic rocks	0.1	0.2
Suboceanic sed.	0.3	0.1
El Wakeel & Riley (1961)		
25 deep ocean calcareous sed.	0.33	0.15
Wedepohl (1969)		
1500 carbonates from platforms	0.07	0.07
Table III 26 dolostone samples	0.66	-
Table IX, 10 dolostone samples:		
EF-17A, 22, 26, 35; JB-55, 82,		
84, 95, 96, 97.	0.69	0.63

The 36 East Fork dolostone samples contain more MnO and P_2O_5 than do common sediments including calcareous sediments. They contain three times the MnO concentration of mafic igneous rocks and almost seven times that of silicic igneous rocks. Clearly, the possibility of manganese having been leached out of the dolostone cannot summarily be dismissed. If, however, leaching were responsible, the problem of why the ore is localized and is not widespread along the dolostone outcrop still remains.

Structural control is important in only one case, that of cut no. one, where fracturing is extensive. Elsewhere, rock deformation is found in the overlying slate, evidenced by slickensides and contorted laminae. Within the ore bodies, deformation is evidenced by shearing of the ore. In other words the ore was already in place at the time of shearing, so shearing of host rocks was not a localizing agent.

There are indications that the dolostone bed becomes more manganeseiferous towards the middle and top, reflecting changing depositional conditions. The indications are not conclusive due to uncertainty about the stratigraphic position represented by a given outcrop. The samples reported in Table III, p. 49 show a clear trend towards more MnO in the middle and top. The writer's samples show a high average MnO concentration (close to 1.30%) in the middle of the dolostone bed at sample locations JB-89, EF-22, and JB-84, all lying west of cut no. three. Elsewhere, the writer's remaining samples do not show any particular stratigraphic trend, but they were not collected in sets across strike in order to detect a trend, with the exception of samples JB-95, 96, and 97. The XRF results for samples JB-95 and 97 (Table VI, p. 70) are at or below the reliability threshold, but sample JB-96 from the middle

of the unit (Plate 1) is slightly richer, at 0.09% MnO. Thus, earlier sampling indicates higher manganese content at the middle and top of the dolostone bed, but the present writer's samples are inconclusive for most parts of the bed.

Manganese Ore

Another problem related to ore genesis is the presence of carbonate rhombs in the ore. That nearly all of the rhombs are perfect euhedra indicates to the writer that they formed relatively unconfined within the soft, black matrix material. If deep burial were the cause (i.e. metamorphism), as suggested by Stose and Schrader (1923, p. 105), then the remainder of the surrounding dolostone should also be coarsely crystalline, which it is not.

An answer to the question of carbonate ore formation, and the occurrence of the carbonate rhombs, is suggested in Soviet literature on manganese carbonate ore. Strakhov (1969, p. 165-67), notes a correlation between the formation of manganese carbonates and water depth. Across a sedimentary basin, manganese carbonate forms in deeper water (more reducing) and the manganese oxides form in shallow water. The transition zone can be as short as one-half kilometer. This particular model does not, however, seem to fit the East Fork situation, where manganese lenses in the dolostone indicate a supratidal setting, not deep water.

Strakhov (1969, p. 207-9) emphasizes the role of diagenesis in manganese carbonate ore bodies. He believes that manganese dioxide is the primary form of manganese deposition, and that during diagenesis of the manganiferous sediments, manganese carbonate forms through the

reduction of manganese dioxide. He recommends that ore formed in this way be termed "sedimentary-diagenetic."

Sapozhnikov (1970, p. 14) endorses the observations of Strakhov (1969) and suggests that in deeper water, manganese carbonates can form from bivalent manganese in solution. Rhodochrosite (MnCO_3), mangano-calcite ($(\text{CaMn})\text{CO}_3$), or oligonite ($(\text{FeMn})\text{CO}_3$) would form, and during diagenesis would become the carbonate ore facies farthest from shore. Sapozhnikov (1970, p. 27) proposes that upwelling currents enriched in dissolved manganese would mix with the near-shore oxygenated water and precipitate manganese partly as oxides and partly as bivalent hydrates. Through reduction and diagenesis, carbonate and oxide facies of a manganese ore body would be formed. Elsewhere Sapozhnikov (1970, p. 20) emphasizes that a low rate of influx of sedimentary material is essential to prevent dilution of the primary ore concentration in the depositional basin.

Ore Genesis at East Fork

The Soviet models deal with ore bodies of manganese carbonate minerals, whereas the carbonate ore at East Fork consists of slightly manganiferous dolomite rhombs in a matrix of calcareous manganese oxide. However, the present writer suggests that the concepts outlined in Soviet literature are applicable to the East Fork occurrence. The upwelling of oceanic water helps to explain both the manganese and phosphorite deposits. The carbonate conglomerate sequence capped by an extensive dolostone bed indicates that a period of shallow-water carbonate sedimentation, with some slumping involved, was followed by a stable period in which dolostone formed under supratidal conditions.

Presumably there would be stagnant pools on the tidal flat where water would tend to have a slightly lower Eh, keeping manganese from marine water and adjacent sediments in solution. Periodic influx of oxygenated sea water would cause precipitation of manganese and also replenish the pool with manganese. Thus, pods and lenses of MnO and calcareous mud would form. With regional (or local) subsidence and influx of silt or sand, as indicated by the conformable overlying sediments at East Fork, conditions allowing MnO precipitation would cease. Upon diagenesis the MnO and calcareous mud would become carbonate ore, containing manganiferous dolomite rhombs set in calcareous banded black matrix. With much later deformation, uplift and erosion, the carbonate ore would be leached and oxidized, accounting for the presence now of both oxide and carbonate ore, and for the fact that oxide ore caps the carbonate ore. In addition, this model would explain the absence of MnO in the northeastern sandy portion of the study area where dolostone occurs. There, the presence of sandstone indicates a higher energy environment where the influx of sediments and oxygenated waters precluded the formation of manganiferous pods.

The data presented in Table IX, p. 73, and Figure 29, p. 74, indicate that the conditions that permitted manganese ore formation also permitted phosphorus to accumulate at levels typical of common sedimentary rocks. But the accumulation of phosphorite is almost to the exclusion of MnO. This suggests to the writer that the phosphorite was deposited later than the manganese when conditions prevailed that allowed better circulation of sea water. That the phosphorite was deposited under higher energy conditions is indicated by coarser sediments and by phosphorite pebbles. Stratigraphic position, as shown

in Plate 5 also indicates later formation of the phosphorite. The western phosphorite, which is laminated, formed near the beginning of the period of changing conditions. It yields upward to coarser phosphorite there and also at the eastern occurrence near Dunn Creek. The phosphorite on Dixon Mountain is difficult to correlate in time because it was deposited a greater distance away, possibly miles away, across a facies change. But its close association to the carbonate conglomerate suggests that it is roughly equivalent to the occurrences at East Fork.

CHAPTER VII

CONCLUSIONS

General

Lack of good exposure, structural complications, and lithologic similarities cause uncertainty in interpretation of the geology in the study area. Regional strike is northeast and dip is steeply to the southeast. Thrust sheets appear to have been thrust from the southeast, and fault planes dip in that direction. The western portion of the area exhibits the straightforward pattern outlined above, but also exhibits tight folding on a local scale. The eastern portion of the study area is much more complex. The Dixon Mountain mass appears to be formed by the stacking of two or more thrust sheets, representing crustal shortening of an area characterized by facies change. The dolostone bed and carbonate conglomerate sequence, persistent throughout much of the study area, is used as a stratigraphic horizon to aid in interpreting the structural problems.

The East Fork manganese deposits formed at the top of a dolostone bed under sedimentary conditions but have been modified by diagenesis and deformation. Carbonate ore is the result of diagenesis of calcareous manganese oxide. Rhombs of dolomite formed in the softer matrix, and reduction of MnO during diagenesis may account for the manganese content of the rhombs. Oxide ore is derived from weathering of the carbonate ore. Phosphorites at East Fork and on Dixon Mountain are slightly younger than the manganese deposits, and were formed under different sedimentary conditions.

Recommendations for Further Work

Inasmuch as the age of the Ocoee Series is still open to question, discovery of fossils would aid in settling the question, at least for the rock units in the study area. The shale lenses on Dixon Mountain described on p. 26 are surprisingly fresh-looking for Precambrian rocks and part cleanly along bedding surfaces. The outcrops were checked briefly for fossils by the writer and none were found. However, they are good candidates for a more systematic examination. Limestone lenses in the carbonate unit also should be searched for microfossils. As shown on Plate 1, there are many carbonate outcrops.

A detailed study of manganese mineralogy at East Fork still needs to be performed. The writer analyzed several ore samples for manganese minerals by means of X-ray diffraction but the results indicated amorphous rather than crystalline material, and thus did not improve on past knowledge. To date the naming of manganese minerals at East Fork is based on field criteria, and not on laboratory analyses.

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A P P E N D I X

A report of hand specimen examination using handlens and binocular microscope to 400X. Grain size classification is based on the Wentworth scale. Color descriptions follow the G.S.A. Rock Color chart.

Measurements were made using a small metric scale and are expressed as fractions rather than decimals, due to limitations of the measuring technique. First group (no. 1-98) is "JB" series, second is "EF" series.

- No. 1: Slate - yellowish gray (5Y7/2) on weathered surface, darker on fresh, deeply weathered, shows alternating dark and light bands. Dark bands are v. fine-grained sand with abundant mica, range from 3 to 5 mm thick; light bands are silty, range 1 to 2 mm thick.
- No. 2: Slate - similar to no. 1. Dominant parting is in the bedding plane with a poorly developed cleavage at 20° to bedding.
- No. 3: Metaconglomerate - light gray (N7) on weathered surface, yellowish-grey (5Y8/1) on fresh. Yellowish coloration is due to much limonite (~20% of surface area). Composition by volume is: 50% clear quartz, subangular grains to 2 mm; 25% feldspar, euhedral grains to 2 mm common (feldspar probably authigenic); 20% limonite, 5% soft black silt that appears to be yielding the limonite. A qtz. vein 8 mm thick is present, with qtz. euhedra, indicating open cavity filling. Weathered surface is pitted, with qtz. grains standing out.
- No. 4: Slate - dark yellowish orange (10YR6/6) on weathered surface, black (N1) on fresh. Bedding is parallel to cleavage, and extremely thin, <1/10 mm to 1 mm, with some micro X-bedding in places. Extensive alteration to sericite and limonite, the latter forming pods 1 mm x 1/4 mm, elongate in the bedding plane. Dark silt and mica give a somewhat salt and peppery texture to the rock, which is not deeply weathered and gives a slatey "clink" when dropped.
- No. 5: Metaconglomerate - grayish orange (10YR7/4) on weathered surface, very pale orange (10YR8/2) on fresh. V. deeply weathered. Composition is 60% subangular qtz., 25% feldspar, 15% sericite and clay minerals, and a trace of limonite. Feldspars are very crumbly and extensively altered. Grain sizes (qtz. and K-spar) range to 5 mm. Sample represents band of gravelly sand in a turbidite sequence.

- No. 6: Dolostone - dark yellowish brown (10YR4/2) on weathered surface, lt. grey (N7) on fresh, well compacted with sugary appearance on fresh fractures. One tiny (1/10 mm) pyrite speck observed, plus scarce dissem. black carbonaceous material. One thin (~1 mm) vein contains scarce pyrite.
- No. 6A: Limestone - very well indurated. Light gray (N7) on fresh or weathered surface. Some fracture surfaces have a sheen from a thin selvage of clay mineralization. Scarce disseminated py. euhedra are present, (<1/10mm), and py. euhedra <1/10 mm are concentrated in scarce black bands ranging to 3/10 mm.
- No. 7: Metaconglomerate - deeply weathered, medium light gray (N6) on weathered surface, dark yellowish orange (10YR6/6) on fresh. Well sorted, most grains are ~1 mm, a few to 4 mm. Composition: subangular qtz. 40%, euhedral and subhedral crumbly feldspar, 40%, sericite and clay minerals 10%, limonite 10%.
- No. 8: Metaconglomerate - similar to previous. Quartz grains range to 10 mm.
- No. 9: Slate - deeply weathered, yellowish gray (5Y7/2) on weathered surface, medium dark gray (N4) on fresh. Similar to No. 4 regarding bedding and texture. Secondary clvg. 30% steeper than bedding.
- No. 10: Slate - dark yellowish orange (10YR6/6) on weathered surface, black (N1) on fresh. Deeply weathered and crumbly. Composition is equivalent to shale or siltstone. Laminae run parallel to cleavage, range from 1/10 to 2 mm.
- No. 11: Slatey siltstone - unweathered. Black, v. fine-grained, grain size <1/10 mm. Largest grains (~1/10 mm) are mica or clay minerals. Laminae plainly visible, 1/4 to 3 mm, parallel to cleavage.
- No. 12: Gravelly quartzite - yellowish gray (5Y7/2) overall. Comp. is: 50% clear or white angular to subround quartz grains, ranging from 1/2 to 3 mm; 25% feldspar as angular grains to 7 mm, and 25% fine, grey matrix. Feldspar is commonly altered to a crumbly white mass but many grains exhibit excellent cleavage.
- No. 12A: Metaconglomerate - very deeply weathered. Medium light gray (N5) on weathered surface, very light grey (N8) on fresh. Consists of 50% subangular to subrounded qtz. grains to 3 mm, 40% subround to euhedral feldspar grains, and 10% slate chips, and clay minerals. Feldspar commonly run to 6 mm diameter and one measures 12 x 9 mm. A slate chip measures 26 x 15 mm. Feldspar occupies the spaces between qtz. grains, is generally crumbly and altered in part to clay. One surface of this specimen shows cockscomb qtz., indicating open cavity filling.

- No. 13: Gravelly metaquartzite - similar to No. 15 except for a slightly higher percentage of dark silt, to about 20%. Scarce flakes of py. are disseminated through the grit. Grit commonly weathered to spongy brown mass. Scarce calcite as noted above.
- No. 14: Gravelly metaquartzite - similar to No. 15 but qtz. grains <2 mm. Weathering to clay is more advanced giving higher clay percent, to about 30%. Medium light gray (N6) on fresh and weathered surfaces.
- No. 15: Gravelly metaquartzite - deeply weathered. Med. lt. gray (N6) on weathered and fresh surfaces. Composed of 50% subangular to rounded clear or milky quartz grains to 2 mm, 30% feldspar in grains up to 8 mm x 3 mm, occurring as in No. 12, 15% dark silt, and 5% limonite apparently derived from the silt. Scarce calcite indicated by weak HCL-reactions visible only under the microscope.
- No. 16: Gravelly metaquartzite - similar to above but w/less feldspar. Composition 75% qtz. grains to 6 mm, 15% feldspar, 10% biotite w/grains to 1 mm.
- No. 17: Shale - v. thin bedded deeply weathered to clay. Alternating light and dark beds, 3 mm to 10 mm thick. Microcross-bedding within beds; individual laminae as thin as ~1/10 mm.
- No. 18: Edgewise conglomerate - Chips of highly calcareous fine-grained sandstone in a sandy matrix. Chips are randomly oriented, measure up to 11 mm thick x 35 mm long. A few rounded pebbles of fine-grained dark reddish brown (10R3/4) sandstone, to 10 mm, are present.
- No. 19: V. fine-grained massive siliceous dolostone - moderate brown (5YR4/4) to dark reddish brown (10R3/4) on weathered surface, medium gray (N6) on fresh. Fresh surface exhibits a sugary texture.
- No. 20: Siliceous dolostone - similar to No. 19. No red sandstone pebbles as in No. 19; has a 5 mm vein of calcite cutting through.
- No. 21: Metaquartzite - dk yellowish brown (10YR4/2) on weathered surface, medium light gray (N6) on fresh. Composition is 90% quartz pebbles to 5 mm, rounded to subangular, milky or clear feldspar, 10%. Calcite cement is present, and also occurs in very fine fractures in quartz grains.
- No. 21A: Limestone breccia - light gray (N7) compact. Brownish gray (5YR4/1) on weathered surface. Breccia structure visible when fresh surface is wet. Angular fragments to 20 mm.

- No. 22: Slate - dark yellowish orange (10YR6/6) on weathered surface, grayish black (N2) on fresh. V. thin bedded, beds 1/10 mm to 10 mm, some microcross-bedding in thicker beds.
- No. 23: Slate - medium light gray (N6) on weathered surface, grayish black (N2) on fresh. V. thin bedded, bedding obscured by deep weathering, beds apparently range from 1 to 3 mm. . Abundant dark silt and abundant mica flakes, <1/10 mm. Cleavage 40° steeper than bedding.
- No. 24: V. fine-grained sandstone or siltstone - Grains <<1/10 mm w/extensive mica. Light olive gray (546/1) on both fresh and weathered surfaces.
- No. 25: V. fine-grained sandstone - moderate brown (5YR3/4) on fresh or weathered surfaces. Composition and grain size as in No. 24. Beds are v. thin, 1 to 4 mm thick. Cross-bedding is marked by black beds 1 mm thick.
- No. 26: Milky quartz with black veins to 3 mm thick. (Qtz. itself is from a 5" vein in sandstone.) Black veins show extensive alteration to limonite. Under 400X, tiny yellow rectangles, v. scarce, are seen - probably pyrite. Black veins may be manganiferous. Specimen exhibits cockscomb qtz. structure.
- No. 27: Med, grained metasandstone with abundant black veins to 5 mm, in places merging to form black zones to 20 mm. Some surfaces of the black material, under 400X are seen to have a micro-colloform structure, w/individual "buds" <.2 mm. Some alteration to limonite, probably indicating pyrite in the black material, which may be MnO.
- No. 28: Very fine-grained metasandstone - moderate brown (5YR4/4) on weathered or fresh surfaces. Sandstone beds to 40 mm are interbedded w/shale beds of 4 to 6 mm w/individual laminae <1 mm. Shaley surface in one area 100 mm x 60 mm shows slickensides.
- No. 29: Slate - moderate brown (5YR3/4) on weathered surface, dark grey (N3) on fresh. Very deeply weathered, which emphasizes alternating light or dark beds to 1 mm thick. Bedding 40° to cleavage.
- No. 30: Limestone - dark yellowish brown (10YR4/2) on weathered surface, med. grey (N5) on fresh. Weathering not extensive. Very dense, compact, with sub-conchoidal fracture. Recrystallization yields XL's to 1/4 mm. Appears to be fairly pure, with ~5% disseminated dark gray (N3) material. Scarce veinlets (1-3 in. apart) of darker material contain ~10% py. cubes to 1/10 mm. Bedding or lamination is evident on weathered surface, barely detectable on fresh, averages 1 mm thick. Some veinlets are colored dark or dark yellowish orange (10YR6/6), or dark yellowish brown (10YR4/2) indicating staining from limonite after py.

- No. 31: Metaquartzite - v. deeply weathered. Dark yellowish brown (10YR4/2) on weathered surface dark yellowish orange (10YR6/6) on fresh due to extensive limonite. Composition is 65% qtz., 25% limonite, and 10% feldspar. Quartz grains are clear or milky, and commonly have pitted surfaces with limonite filling the pits, indicating probably py. in the qtz. Grains are subangular to rounded, range to 2 mm. Quartz veins to 4 mm are common. Earthy limonite masses to 10 mm are common. Feldspar grains are angular, range to 2 mm.
- No. 32: Dolostone - dense, homogeneous; brown gray (5YR4/1) on weathered surface, medium gray (N5) on fresh. Not deeply weathered. V. fine-grained <1/4 mm, w/scarce flecks of black material disseminated throughout, and scarce 1 mm thick veinlets of black dolomite that show yellow areas ~1 mm across. Such zones, under 400X contain very small py. euhedra, <1/100 mm. Bedding or laminae are not visible, but specimen parts neatly into 22 mm-thick pieces.
- No. 33: V. fine-grained metasandstone - w/highly contorted structure. Moderate brown (5YR4/4) on weathered surface, gray on fresh. Alternating light or dark laminae average 1 mm thick, are tightly folded, with folds measuring 15 mm crest-to-crest. Grain size <1/10 mm, composition undetermined, but scattered flakes of muscovite are visible. Specimen is very deeply weathered, and limonite is pervasive with some earthy masses to 15 mm.
- No. 34: Quartzite - very deeply weathered. Dark reddish brown (10R3/4) to dark yellowish orange (10YR6/6) on weathered or fresh surface. Composition is 85% quartz, 10% limonite cement, and 5% feldspar. Quartz grains range from angular to round, and range in size to 5 mm, average size ~1.5 mm.
- No. 35: Siltstone - Dark gray (N3) on weathered or fresh surface, deeply weathered. Composition is 50% dark silt, 25% limonite, 25% muscovite, w/flakes to 1/3 mm. Lamination or bedding not evident.
- No. 36: Siltstone - medium light gray (N6) on weathered and fresh surfaces. Clay-size particles slightly gritty when chewed. Specimen contains ~5% scattered black flecks, composition unknown. Very finely laminated - laminae average ~1/2 mm.
- No. 37: Limestone - brownish gray (5YR4/1) on weathered surface, dark gray (N3) on fresh. Dense, compact, grain size undeterminable under 400X. Contains limestone chips; (one is 20 x 6 mm) in random orientation. Clustered flakes of py. noted along a cemented fracture or vein ~1/4 mm across. Flakes are in rounded masses to ~1/10 mm, flakes themselves are of subangular nondescript shapes, v. small (~1/100 mm).

- No. 38: Metaquartzite - deeply weathered - yellowish gray (5Y7/2) on weathered or fresh surface. Massive structure. Composition is 50% angular to rounded qtz. to 4 mm, 25% feldspar, angular grains to 4 mm, 25% interstitial dark silt.
- No. 38A: Siltstone - grayish orange (10YR7/4) on fresh or weathered surface, deeply weathered. Beds are 2 mm to 4 mm thick. Largest visible grains under 400X are muscovite flakes 1/4 mm dia. Composition is: grayish orange (10YR7/4) clay and silt particles 60%, mica 20%, dark silt 20%.
- No. 39: Conglomerate of slate chips, quartz grains, calcite grains, in a limestone matrix. Yellowish gray (5Y7/2) on weathered surface, grayish orange (10YR7/4). Bedding is crude, with calcite-sand beds to 30 mm. Calcite grains typically measure 1/2 mm, and are angular. Slate chips are angular to rounded, range to 15 x 2 mm. Quartz grains range to 3 mm are well rounded. Limonite is common throughout, with pure limonite zones (earthy masses) to 15 mm dia.
- No. 40: Siltstone - Medium gray (N5) on fresh or weathered surface. Deeply weathered but still very competent. Grain size <<.1 mm; abundant small mica flakes. Bedding ranges from 1 mm to 20 mm.
- No. 41: Limestone - dark yellowish orange (10YR6/6) on weathered surface, medium light gray (N6) on fresh. Weathered surface is irregular, suggesting a conglomeratic texture but fresh surface shows a massive structure and sugary texture. Grain size <<<.1 mm. One corner of specimen, in a zone 10 x 20 mm, contains several round clear quartz eyes to 1/2 mm. One pyrite cube measuring ~1/50 mm was observed. Limonite staining on fractures is common.
- No. 42: Shale - yellowish gray (5Y7/2) to very light gray (N8), on fresh or weathered surface. Fissile, parting into 5 to 10-mm thick plates. Laminae range from 1/10 to 1/2 mm. Texture is exceedingly fine grained - no grains or impurities visible under 400X. Specimen feels talcose.
- No. 43: V. fine grained m-sandstone - Medium light gray (N5) on weathered surface, medium light gray w/ thin laminae on fresh. Deeply weathered but competent. Laminae range from 1/2 to 6 mm. Grain size ~1/10 mm.
- No. 44: Very fine grained metasandstone - similar in all respects to No. 43.
- No. 45: Limestone - grayish orange (10YR7/4) on weathered surface, light gray (N7) on fresh. Weathered surface exhibits bedding from 1 to 3 mm thick, and cross-bedding. Weathering on fractures and bedding planes shows limonite alteration. Fresh surface is massive and sugary in texture; grains <1/4 mm.

- No. 46: Metasandstone - mottled med. gray (N5) and moderate brown (5YR4/4) on weathered surface, dark gray (N3) on fresh. Subround quartz grains to 8 mm, averaging 2-3 mm, occur in a dark gray (N3) matrix thought to be P_2O_5 . Where quartz grains are coarser, the structure consists of open voids lined with limonite between nearly all of the grains. Similar voids occur, but not as commonly, where the specimen consists of massive matrix material. The specimen has, overall, a pitted punky appearance but is actually a very competent rock. Thin white quartz veins to 1 mm are common.
- No. 47: V. fine-grained metasandstone - Similar in all respects to No.'s 43 and 44.
- No. 48: Limestone - grayish orange (10YR7/4) on weathered surface, light gray (N7) on fresh. Massive, with a sugary texture, grains $\sim 1/4$ mm. One small zone 15 mm square contains numerous yellow metallic irregular flakes, probably py.
- No. 49: Limestone - similar color and texture to 48. Metallic flakes more abundant, plus $\sim 10\%$ black or brown impurities. In one area 10 x 10 mm, several metallic yellow cubes $\sim 1/10$ mm were noted - probably py. Fresh surface exhibits laminae ~ 1 mm thick.
- No. 50: Slaty siltstone - dark yellowish brown (10YR4/2) on fresh or weathered surfaces. Laminae range from $1/2$ to 3 mm, grain size $< 1/10$ mm. Abundant mica ($\sim 25\%$), remainder is dark silt. Excellent cleavage, at 35° to laminae.
- No. 51: Meta-subgraywacke - extremely well indurated, and very fresh. Grayish brown (5YR3/2) on weathered surface, gray (N5) on fresh. Composition is 75% quartz, with grains to 3 mm, averaging $\sim 1/2$ mm; 20% dark silt that commonly contains zones altered to limonite, and also contains scarce dissem. py. flakes $< .1$ and very scarce py. masses to $1/2$ mm; plus $\sim 5\%$ biotite and muscovite.
- No. 52: Meta-subgraywacke - deeply weathered, grayish brown (5YR3/2) on weathered surface, dark yellowish orange (10YR6/6) on fresh (due to extensive limonite). Composition is 40% quartz, well-rounded to subround grains that range to 10 mm, average $1-1/2$ to 2 mm; 40% feldspar, grains average 1-2 mm; 10% slate chips or rounded fragments to 7 mm; and 10% silt that is extensively altered to limonite.
- No. 53: Carbonate cgl. plus slate and sandstone - specimen represents interface of carb. cgl. w/non-carbonate clastics. Dark yellowish orange (10YR6/6) on weathered surface, yellowish gray (5Y7/2) on fresh; very fine grained ls. is light olive gray (5Y6/1), slate is light gray (N7), feldspathic ss is intermediate. Feldspar grains are angular, average $1/2$ mm.

No. 53

(Cont'd: Cement is calcareous. A small patch of very soft ($H < 4$) grayish yellow green (5GY7/2) textured material, 3 x 1 mm was noted at the edge of the feldspar sand - possibly gypsum. Composition: 50% v. fine-grained limestone, 25% feldspar sand, 5% quartz (grains to 3 mm) 20% slate. Specimen is crudely zoned: feldspathic sand/carbonate/slate. Appears to be float; not in place.

No. 54: Dolostone - very fresh, very well indurated - possibly due to quartz grains or SiO_2 cement. Light brown (5YR6/4) on weathered surface, dark yellowish orange (10YR6/6) on fresh. Weathered surface exhibits graininess not seen on fresh surface - grains are qtz. Specimen is cut by several 1 mm CaCO_3 veinlets. Composition: 75% dolomite, (in part slightly silty), 25% quartz grains to 1 mm. Dolomite grains $< 1/2$ mm.

No. 55: Dolostone - pale yellowish brown (10YR6/2) on fresh or weathered surfaces, weathered only on outer 2 mm. Extensively cut by qtz. veinlets to 2 mm. Contains much (~10%) black material as clots on veinlets; could be MnO .

No. 56: Quartzose dolostone - moderately weathered, pale yellowish brown (10YR6/2) on weathered surface, mottled grayish brown (5YR3/2) on fresh. Composition is 75% dolomite, pale yellowish brown, very fine grained; 15% quartz to 1 mm, rounded to angular, 10% light olive gray silt (5Y5/2) in masses to 5 mm, and rounded slate fragments to less than 1% of the total volume. Pyrite occurs in specks or euhedra to 1 mm, and is most common in the quartzose areas (where euhedra may form ~25% of an area 2 x 2 mm) or in the silty areas.

No. 57: Manganiferous (?) shale - very deeply weathered. Shale is dusky yellow (5Y6/4), very soft, extensively sheared, and cut by MnO (?) veins. MnO (?) appears as black coatings on fracture surfaces or as open cavity fillings. Under 400X, colloform structures can be seen, w/individual "buds" ~1/10 mm (specimen is float; not in place).

No. 58: Metaquartzite - v. well indurated, relatively unweathered. Fresh surface is mottled dark reddish brown (10R3/4) and white, exposed surface is medium light gray (N6). Quartz grains subround, to 6 mm. Some zones exhibit open cavities w/qtz. crystals 2 mm long projecting from the walls. Hematite stains impart a reddish cast; earthy hematite fills a 2 mm cavity.

No. 59: Bedded dolostone - yellowish gray (5Y7/2) on fresh or weathered surface. Weathering not extensive. Beds range from 10 to 20 mm. Laminae range from 1 to 4 mm. Very fine grained - average size ~1/10 mm. Contains about 10% silt. Very well indurated, very poor rxn to HCL.

- No. 60: Dolostone - yellowish gray (5Y7/2) on weathered surface, medium light gray (N6) on fresh, relatively unweathered. Dolomite grains average 1/10 to 1/2 mm. Dissem. py. flakes <1/10 mm are common, as are py. euhedra ranging from 1 to 1-1/2 mm. Pyritic zones to 2 mm are scarce. Specimen is cut by numerous calcite veins to 2 mm, spaced 2 to 10 mm apart and roughly parallel.
- No. 61: Limestone - light brownish gray (5YR6/1) on fresh or weathered surface - relatively unweathered. Sugary texture, very fine grained. Abundant disseminated grayish brown (5YR3/2) spots ~1 mm dia. indicate possible presence of goethite after pyrite.
- No. 62: Siltstone - dark yellowish brown (10YR4/2) on weathered surface, medium dark gray (N5) on fresh, not deeply weathered. Laminae are indicated by streaks (<1/10 mm) of white or brown. Laminae measure 1/10 mm to 1 mm. Specimen is very well indurated, not fissile, and appears to have the composition of graywacke, but composition is indeterminate due to small grain size (<1/10 mm). Mica is common. Small scarce patches of py. to 1/2 mm are present.
- No. 63: Siltstone similar in every respect to No. 62.
- No. 64: Siltstone - dark yellowish brown (10YR4/2) on fresh or weathered surface. Structure as in No.'s 62-63. Calcareous cement indicated by weak rxn w/HCL. Weathered somewhat more than 62-63.
- No. 65: Dolostone - light olive gray (5Y6/1) on fresh or weathered surface. Generally fine grained (<1/10 mm) but a few grains range to 1/4 mm. Moderately weathered.
- No. 66: Siltstone - dark yellowish brown (10YR4/2) on fresh or weathered surface, very deeply weathered, very highly contorted. Laminae range from 1/2 to 1 mm, are tightly folded into folds that measure as little as 8 mm crest-to-crest. Specimen is very crumbly, also exhibits slickensides.
- No. 67: Limestone - light gray (N7) on weathered surface, light brownish gray (5YR6/1) on fresh. Relatively underweathered. Very fine-grained (<<1/10 mm) sugary texture. Exhibits crude bedding, 1 to 25 mm thick. One 10 mm bed is grayish red (5R4/2) in color.
- No. 68: Metaquartzite - lt. gray (N7) on fresh or weathered surface. Very deeply weathered, crumbly. Composition is 75% quartz, 25% feldspar 2/few unaltered crystals - occurs mostly as white matrix material. Limonite staining common. Grains typically measure 2-3 mm. One qtz. pebble, subround and oblong, measures 40 x 20 mm, is sheared, with the sheared surface corresponding to slickensided surface on the specimen.

- No. 69: Shale - free of sand, very light gray (N8), abundant mica flakes to 1/10 mm. Specimen represents a 13 mm clayey layer in a shale unit.
- No. 70: Siltstone - very deeply weathered, clayey-texture. Laminae range from 1/2 to 6 mm. Color is streaked black and dark yellowish brown (10YR4/2) due to numerous laminae having a high carbonaceous content.
- No. 71: Limestone - medium dark gray (N4) on weathered surface, med. light gray (N6) on fresh. Extremely fine grained. Weathering penetrates only the outermost few mm, or along fine joints. Weathered surface shows breccia structure, w/one angular fragment measuring 15 x 50 mm. Small py. euhedra, <1/10 mm, are disseminated throughout and also occur in small clusters to 1 mm.
- No. 72: Siltstone - very deeply weathered, very crumbly. Light brown (5YR5/6) overall. Parts into layers 15 mm thick; has one medium light gray (N6) lamination 1/3 mm thick. Contains ~10% disseminated black silt.
- No. 73: Metaquartzite - w/grains in "fine sand" range (1/8-1/4 mm), Brownish gray (5YR4/1) on weathered surface, medium gray (N5) on fresh. Moderate weathering throughout. Bedding ranges from 1 to 10 mm. Slight CaCO₃ content indicated by weak rxn x/HCL.
- No. 73A: Siltstone - pale brown (5YR5/2) deeply weathered and soft, shot through by anastomosing contorted black veinlets, possibly of MnO, but no microcolloform structure was observed under 400X. Specimen is 50% black material, 50% siltstone.
- No. 74: Dolostone breccia - brownish gray (5YR4/1) on weathered surface, medium gray (N5) on fresh. Contains approximately 20% subangular quartz grains to 1 mm. Scarce disseminated py. flakes <<1/10 mm are present. Some dolostone fragments contain approx. 10% py. dust or euhedra to 1/10 mm. Some fracture surfaces exhibit a slickenside-like polishing.
- No. 75: Limestone conglomerate - dark gray (N3) siltstone matrix w/tan limestone fragments to 30 mm. L/S. fragments constitute ~25% of the volume. Specimen does not part neatly - surfaces are very irregular; specimen has a somewhat contorted aspect.
- No. 76: Limestone - medium dark gray (N4) on fresh surface, light olive gray (5Y6/1) on weathered. Bedding is irregular, with a 20 mm thick limestone layer pinching-out, forming "boudin" measuring 70 x 20 mm. Carbonaceous shale partings wrap around the "boudin." Fine fractures in the shale are cemented by calcite.

- No. 76A: Limestone conglomerate - medium gray (N5) on fresh surface, light olive gray (5Y6/1) on weathered. Exhibits flaser structure; limestone beds ranging from 2 to 15 mm thick are warped and broken, with beds and broken pieces separated by selvages and masses of carbonaceous shale.
- No. 77: Limestone-massive, grayish black (N2), w/numerous 2 mm veinlets of calcite. Grain size averages 1/4 mm, with many calcite grains in the veinlets to 1 mm. Scarce, disseminated py. occurs, as well as a concentration in one 10 mm diameter area, occupying ~25% of the volume therein. Pyrite euhedra average 1/10 mm, w/some irregular masses to 1 mm. Specimen is relatively unweathered.
- No. 78: Similar in all respects to No. 77 except that py. is not clustered. Specimen exhibits a subconchoidal fracture and a very dense, fine grained texture.
- No. 78A: Metaquartzite - medium lt. gray (N6) very deeply weathered, massive. Quartz grain size averaging 1/2 mm. Specimen contains 10-25% pyrite occurring as striated euhedra that range from 1/10 to 1/4 mm, imparting a noticeable sparkle and heaviness.
- No. 79: Earthy, punky material - dusky brown (5YR2/2). Extremely fine grained, <<<1/10 mm, except for scattered grains of Qtz. and calcite ~1/10 mm in size. Weak rxn w/HCL.
- No. 80: Siltstone - banded moderate brown (5YR3/4) and brownish gray (5YR4/1), deeply weathered, finely laminated. Grain size <1/10 mm, laminations range from 1/4 to 1-1/2 mm. Cleavage (well-developed) is 35° steeper than bedding.
- No. 81: Limestone - banded grayish black (N2) and medium gray (N4), moderately weathered, very fine grained, <1/10 mm. Laminations range from 1/2 to 12 mm; thin laminae are typically lt. gray and highly calcareous, thick laminae are black and carbonaceous.
- No. 82: Dolostone - yellowish gray (5Y7/2) relatively unweathered. Grain sizes range from 1/10 to 1/2 mm, imparting a sugary texture.
- No. 83: Conglomeratic siltstone - light olive gray (5Y6/1) overall, fresh. Contains clasts of limestone or calcareous sandstone, plus vugs filled with limonite. Matrix is carbonaceous silt w/grain size <1/10 mm. Clasts are subround to angular to chip-like, ranging from 2 mm subround limestone and sandstone clasts to 20 x 2 mm chips of limestone.
- No. 84: Dolostone - medium light gray (N6) on surface. Grain size <1/10 mm, sugary texture. Contains scarce, scattered, round 1/2 mm Qtz. grains. Specimen is thoroughly diced by fine 1/8 mm quartz veinlets, spaced 1 mm to no more than 15 mm apart.

- No. 85: Arenaceous shale - dark gray (N3) overall, deeply weathered. Laminae range from 1/4 mm to 1 mm. Grain size <1/10 mm. Some laminae are nearly 100% clean subangular qtz. grains; other laminae are very fine-grained, black carbonaceous silt. Parting is in the bedding plane.
- No. 86: Calcareous argillite - dark gray (N3), highly carbonaceous - appears graphitic. Finely laminated, laminae range 1 to 5 mm, show small scale gentle warping. Poorly developed irregular parting 70° steeper than bedding.
- No. 87: Limestone - medium gray (N5), fine-grained, <1/10 mm, moderately weathered. Structure consists of irregular lenses, ranging from 10 x 1 mm to 60 x 6 mm, separated by thin anastomosing selvages of silt. Very scarce dust-sized (<<<1/10 mm) specks of py. disseminated throughout.
- No. 88: Siltstone - moderate yellowish brown (10YR5/4), very deeply weathered, friable to earthy. Extensive secondary mica flakes to 1/2 mm throughout. Specimen is very porous and vuggy, w/some vugs filled w/limonite. One 15 mm vug is surrounded by silty matrix that has grayish purple (5P4/2) cast, suggesting MnO or P₂O₅ or FeO. Other zones in the specimen are similarly colored. One area 10 x 20 mm exhibits limonite boxwork. Quartz grains average 1/10 mm, one 3/4 mm qtz. veinlet was observed.
- No. 89: Dolostone - medium light gray (N6), massive, unweathered. Siliceous w/weak rxn in HCL. Extensively dissected by qtz. veinlets from 1/4 to 2 mm thick, spaced 2 to 20 mm apart and running generally parallel. Pyrite dust flakes very scarce and dissem. except where concentrated at a calcite veinlet 1 mm thick. There, py. euhedra range to 1/10 mm.
- No. 90: Siltstone - medium dark gray (N4) overall, deeply weathered. Laminations from 1/10 to 1/2 mm, grain size <1/10 mm. Alternate laminae are medium light gray (N6) or black. Composition is about 25% qtz. grains, 75% black carbonaceous silt.
- No. 91: Sandstone - dark yellowish orange (10YR6/6) on fresh surface, yellowish gray (5Y7/2) on weathered. Very deeply weathered. Yellow color is due to extensive limonite. Composition is 25% limonite matrix, 75% clear subround qtz. grains from 1/4 to 3/4 mm.
- No. 92: Subgraywacke - dark yellowish brown (10YR4/2) overall, deeply weathered. Composition is 40% clear subround qtz., 40% white euhedral feldspar (possibly secondary) and 20% silty matrix extensively altered to limonite. Grain size is typically 1/2 mm, one qtz. grain measures 2 mm.
- No. 93: Float: missing.

- No. 94: Massive phosphorite - dusky blue (5PB3/2) overall, cut by a network of milky quartz veinlets and mottled or dotted with grayish orange (10YR7/4) patches. Qtz. veinlets range from 1 to 4 mm thick, are roughly parallel, spaced from 1 to 10 mm apart. Rectangular pits from 1 to 6 mm are common, are filled w/white earthy (clay?) material possibly sericite after feldspar. Feldspar grains range to 7 mm.
- No. 95: Dolostone - medium light gray (N6) overall, unweathered. Grain size $<<1/10$ mm; texture is sugary. Specimen is cut by several 1 mm qtz. veinlets, and is streaked by one 1/2 mm black veinlet.
- No. 96: Dolostone - medium light gray (N6), sugary texture, grain size $<<1/10$ mm. Appears massive on fresh surface but weathered surface shows laminae from 1/10 to 4 mm. Specimen contains ~10% impurities including v. scarce py. grains $<<<1/10$ mm. Very fresh appearance - unweathered except for a thin rind.
- No. 97: Dolostone - light brownish gray (5YR6/1) on fresh surface. Sugary texture, grain size $<1/10$ mm, cut by several qtz. veinlets from 1 to 3 mm. One fracture surface is covered w/calcite crust w/cleaved XL's to 4 mm. One dust-sized ($<<<1/10$ mm) py. speck noted.
- No. 98: Siltstone - deeply weathered, marked by alternate grayish orange (10YR7/4) and medium gray (N5) laminae. Dark laminae range from 1/2 to 2 mm; light laminae from 1/10 to 2 mm, are generally much thinner than dark laminae. Bedding is extremely distorted, exhibiting chevron folds ~4 mm crest-to-crest. Also shows X-bedding and small (1 x 8 mm) light colored pods. Light material is somewhat more granular than the dark; clusters of py. (1 mm grains) occur rarely, in the dark material.

End Of Regional Hand Specimens ("JB" Series)

EAST FORK (EF) SERIES

- EF-1 Phosphatic sandstone - mottled white and light gray (N7) on fresh surface, yellowish gray (5Y7/2) on weathered, stained, w/FeO. Deeply weathered. Not in place. One surface shows slickensides on which pyrolusite dendrites occur. Composition is 50% medium gray (N5) phosphatic matrix, 25% clear subround qtz. grains from 1/4 to 2 mm, 10% feldspar as anhedral grains to 2 mm, and 15% numerous qtz. veinlets typically 1/2 to 1 mm thick ranging from 2 mm thick plus extensive limonite. Small flecks of pyrite are common, and are clustered in several areas into masses ~3 mm in dia.

- EF-2 Similar to EF-1 and also exhibits several medium light gray (N6) earthy patches and a 7 mm-thick qtz. vein w/open cavities. Not in place.
- EF-3 Phosphatic silty sandstone - poorly consolidated, earthy, deeply weathered, medium gray (N5), w/pod-like zones of dark greenish gray (5GY4/1) and medium bluish gray (5B5/1) material. Also contains light gray (N7) earthy pods from 4 x 2 mm, to 20 mm dia. Specimen is 75% silt-sized matrix, 20% clear subround qtz. grains typically 1/2 mm diameter, ranging to 2 mm, and ~5% anhedral white feldspar.
- EF-4 Phosphatic sandstone - mottled w/yellowish gray (5Y7/2) and white due to quartz grains, phosphatic grains, and limonite. Composition is: 75% phosphate pebbles, typically soft and well rounded, but also in chips. Pebbles typically are 2 mm dia., chips 2 x 4 mm; 25% clear or milky qtz. grains, round to subangular, 1/2 to 3 mm. Specimen is crumbly - grains easily separated. Not in place.
- EF-5 Phosphatic siltstone - mottled medium light gray (N6), dark yellow orange (10YR6/6) and grayish purple (5P4/2); deeply weathered. Alternate laminae are light and dark, ranging overall from 1/2 to 3 mm. Light laminae range from 1/2 to 1-1/2 mm, are very soft and earthy, somewhat grainier than the dark laminae which range from 1/2 to 3 mm. Specimen is cut by a 3 mm thick qtz. vein.
- EF-6 Dolostone - light gray (N7) on fresh surface, dark yellowish orange (10YR6/6) on weathered; relatively unweathered. Specimen exhibits a sugary texture; grain size average $<1/10$ mm. Specimen is cut by a 2 mm qtz. veinlet. Some fracture surfaces are coated with a veneer of MnO, and very small (barely detectable at 400X) pyrite (?) flecks are disseminated throughout, and constitute $<1\%$ of the rock mass.
- EF-7 Manganese ore - cut by numerous clear qtz. veinlets that form a boxwork where MnO has been removed. Clear qtz. veinlets are 1/4 to 2 mm thick, and constitute about 25% of the mass of the specimen. Manganese has a jagged scoriaceous appearance, but some vugs are lined with smooth curved domes of shiny manganese, and some with microcolloform MnO.
- EF-8 Manganese ore - generally massive but many zones are scoria-like. Platy 1 mm domes of colloform structure are common.
- EF-9 Mineralized siltstone, mottled grayish purple (5P4/2) and grayish orange (10YR7/4). Soft and earthy in places, hard, manganiferous in the remainder. Specimen is about 50% earthy materials, 50% MnO(?). A single 1 mm clear qtz. vein occurs, and several veinlike aggregations of pyrite (euhedral to anhedral) in 1/2 mm grains occur. Some vugs are lined w/microcolloform MnO. Sedimentary structure has

EF-9

(Cont'd) been destroyed. Structure consists of masses of siltstone surrounded and invaded by manganiferous material.

EF-10

Siltstone - highly altered, and mineralized by MnO(?). Coloration same as EF-9. Sedimentary structure has been destroyed. Structure consists of clots of siltstone to 20 mm surrounded by masses and networks of MnO(?). The manganiferous(?) component (~25%) of the specimen is by far the most competent - appears to have intruded into the sediment, disrupting the sedimentary structure.

EF-11

Boxwork of qtz. veins from 1/5 to 1 mm thick, intersecting at various random angles, spaced from 1 to 10 mm apart. Black veinlets (MnO?) present also. Many cavities formed by boxwork are filled w/limonite or silt-sized material. Specimen ranges in color from mottled black and pale yellowish orange (10YR8/6) and dark reddish brown (10R4/6).

EF-12

Earthy, porous residue - moderate brown (5YR3/4), very lightweight. A coherent but friable mass; shows no rxn w/HCL. Under 400X, a few tiny reflections from cleavage or XL faces can be detected - possibly mica.

EF-13

Manganese ore - generally black overall but many cavities up to 10 x 30 mm are filled with pale reddish brown (10R5/4) hematite(?). There are also numerous qtz. veins, 1/2 to 3 mm thick. Some vugs are filled w/pale blue (5B6/2) clay. Manganiferous areas are vesicular, w/walls of vesicles exhibiting colloform structure. Some qtz. veins have hollow portions also containing colloform manganese. Near one qtz. vein (within 3 mm) the manganese ore contains abundant qtz. "eyes," angular to round, 1/4 to 1/2 mm dia. Pyrite is scarce overall, but some minor local concentrations exist. Grains are subhedral, 1/10 to 1/4 mm.

EF-14

Manganese ore - light olive gray (5Y5/2) overall, highly fractured, somewhat earthy looking w/unaided eye and also under microscope, suggesting mineralized sediment although no sedimentary structure is visible. Close-spaced (1-5 mm) boxwork of qtz. veinlets occurs in a 20 x 20 mm area. Scarce disseminated pyrite in 1/10 mm euhedra occurs. Qtz. "eyes" occur as EF-13 but over a larger portion of the specimen.

EF-15

Manganese ore, high grade. Black overall w/hematite stains and a hematite filling in some small (~2 mm) vugs. Colloform structure throughout, with some individual domes to 2 mm.

- EF-16 Manganese ore - (high grade). Massive mottled black and dark reddish brown (10R3/4). Hematite stains and zones to 20 mm are common. Pyrite, as cubes to 2 mm and pyritohedra to 3/4 mm, is common, and constitutes approx. 5% of the mass of the sample. Pyrite occurs throughout the manganese ore and rarely in qtz. veins. Specimen is cut by numerous parallel qtz. veinlets 1/4 to 3 mm thick, spaced 2 to 10 mm apart.
- EF-17 Quartz vein material - milky, 12 to 18 mm thick. Central portion is open to 5 mm, and exhibits cockscomb structure.
- EF-17A Dolostone - pale yellowish brown (10YR6/2) on fresh surface. Grains to 1/4 mm. Contains numerous qtz. veinlets 1 to 2 mm thick. Close-spaced fracture system (1-3 mm) w/black fracture filling - possibly MnO.
- EF-18 Earthy material - moderate brown (5YR3/4) - same in all respects to EF-12.
- EF-19 Siltstone - deeply weathered to a clay-like texture. Coloration is mottled medium gray (N5) and pale yellowish brown (10YR6/2). Brown portions contain abundant cubic pits to 1/4 mm filled w/earthy hematite. Specimen is cut by numerous anastomosing veinlets of MnO(?), subparallel to bedding. Specimen is cut by several qtz. veinlets to 1/3 mm, forming a boxwork in one 8 x 8 mm zone. One 3 mm-thick veinlet is 50% pyrite euhedra measuring 1/10 to 1/4 mm. Specimen is brittle and crumbly.
- EF-20 Manganese ore - abundant limonite staining and some vesicles filled w/limonite. Specimen appears vesicular or sintery, and is cut by a 1 mm qtz. veinlet.
- EF-21 Siltstone - dark yellowish orange (10YR6/6), deeply weathered. Contains ~5% py. as euhedra and poorly formed cubes to 1/4 mm, plus MnO(?) selvage along some fractures. Py. also occurs concentrated in a 2 mm-diameter zone where it constitutes 50% of the mass.
- EF-22 Dolostone - medium light gray (N6) overall w/highly pyritic zones giving yellowish cast. Also shows dusky red zones (5R3/4) from FeO after py. Dolomite XL's range from 1/10 to 1/4 mm. Py. dust is disseminated throughout - probably constitutes 1%+ of rock mass, and also is concentrated in zones to 7 mm dia.; occurs as anhedral clots, often exhibiting peacock tarnish. Chalcopyrite not evident from scratch test.
- EF-23 Phosphatic sandstone - grayish blue (5PB5/2) overall, moderately weathered. Composition is 65% grayish blue matrix, 20% white feldspar as hard cleaved grains or softer rounded masses, from 1/2 to 3 mm. (One oblong

EF-23

(Cont'd) 3 x 5 mm white mass contains a 2 mm round qtz. grain); 10% clear quartz grains, angular to round, 1/2 to 2 mm, 5% milky qtz. veinlets 1/4 to 1 mm thick, in random orientation, spaced 3 to 20 mm apart. Specimen is very well indurated and gives a clinky sound when struck.

EF-24

Bedded phosphorite - streaked grayish blue (5PB5/2) and dark yellowish orange (10YR6/6). Beds are ~10 mm thick, somewhat contorted; phosphatic laminae range from 1/2 to 1 mm thick. Composition is 75% blue phosphorite, 15% feldspar (secondary) as round to rectangular crumbly grains, and 10% quartz, as clear angular grains to 2-1/2 mm. Size-grading within individual laminae or beds, and in the specimen overall is indeterminate. Stratigraphic setting indicates overturning.

EF-25

Metagraywacke - medium gray (N5) w/very pale orange (10YR8/2) flecks of weathered feldspar. Very well indurated. Composition is 35% qtz. grains, clear or milky, angular, to 2 mm; 30% silty matrix material; 25% feldspar typically as, weathered crumbly masses, angular to round, measuring to 1 mm dia.; 10% py. anheda, disseminated throughout, and also commonly clustered into 4 mm rounded areas.

EF-26

Dolostone - pale yellowish brown (10YR6/2) on fresh surface. Grains range from 1/10 to 1/4 mm. Some regions are dark suggesting presence of impurities or manganese. Also, several 3/4 mm round black zones are present. A network of fine clear to milky qtz. veins cuts the specimen; they are 1/8 to 1-1/2 mm thick. Milky qtz. forms a 4 mm round patch in the dolostone and encrusts a fracture surface w/1 mm grains.

EF-27

Pyritic quartz - speckled light gray (N7) and brassy appearance. Very well indurated; tough, heavy. Anhedral to euhedral py. grains 1/4 to 1/2 are common (rarely to 1-1/2 mm) plus nondescript clots to 2 mm - all set in a matrix of clear to milky quartz. Composition is 50% py., 50% qtz. Dark areas (rare, <10 mm) may suggest MnO. Not in place, collected from mine dump.

EF-28

Calcareous dolostone - (intermediate rxn to HCL), brownish gray (5YR4/1). Cut by several CaCO₃ veins to 1 mm. Grains range from 1/10 to 1/4 mm.

EF-29

Highly oxidized colloform manganese cut by several qtz. veins from 1/4 mm to 4 mm thick. Specimen is mottled pale yellowish orange (10YR8/6) and dark reddish brown (10YR3/4), with dark areas of MnO. Individual domes range to 4 mm; most domes measure 1/2 to 1 mm. Specimen is 50% FeO, 40% MnO, 10% qtz. veins.

- EF-30 Manganiferous pyritic calcareous siltstone - laminae are indicated by parallel manganese selvages $\sim 1/2$ mm apart. Also manganese as black specks is disseminated throughout. Pyrite euhedra $1/10$ to 2 mm occur throughout. Qtz. veins 2 to 7 mm thick cut the specimen in several places.
- EF-31 Manganese ore - dusky brown (5YR2/2) to dusky blue (5PB3/2), massive colloform structure overall, but with some vesicular areas commonly exhibiting $1/4$ - $1/2$ mm vesicles, rarely ranging to 10 mm. Colloform domes range $1/4$ to 1 mm commonly; a few range to 5 mm. Specimen is crumbly.
- EF-32 Pyritic metaquartzite - lt. gray (N7) overall. Angular Qtz. grains range from $1/4$ to $1/2$ mm. Pyrite is disseminated throughout, grains measure $< 1/10$ mm, constitute $\sim 10\%$ of rockmass. Black impurities scattered throughout.
- EF-33 Limestone - grayish brown (5YR3/2) XL's $1/10$ - $1/5$ mm, strong rxn w/HCL. Scarce dissem. py. flakes $< 1/10$ mm. Similar to EF-28.
- EF-34 Dolostone - medium gray (N5) overall, grains $< 1/4$ mm. Weak rxn w/HCL. Cut by a 13 mm milky Qtz. vein. Fracture surfaces are coated w/shiny black selva, and dolomite is quite dark in places, possibly manganiferous.
- EF-35 Dolostone - medium lt. gray (N6) overall, grains $1/10$ - $1/2$ mm. Moderate to weak rxn w/HCL. A 10 x 10 mm zone is considerably darker than the rest of the specimen and exhibits black intergranular filling - possibly MnO.
- EF-36 Siltstone - olive gray (5Y4/1) overall. Laminae $1/2$ -1 mm thick. Very well indurated and "slaty."
- EF-36A A gossan-like mass partly earthy and vesicular, partly massive and indurated; mottled grayish red purple (5RP4/2), moderate yellow (5Y7/6) and dark reddish brown (10R3/4). (Well-indurated material is purplish-brown.) Pyrite euhedra, typically $1/2$ mm, rarely to $3/4$ mm, are concentrated in zones ~ 3 mm across, in both earthy and massive material. Specimen is cut by a $1/2$ mm Qtz. vein.
- EF-37 Siltstone - deeply weathered, mottled black and grayish purple (5P4/2). Laminae average $1/2$ mm thick, are contorted. Some laminae contain subangular clear Qtz. grains to 1 mm. In places, purple laminae are parallel to sub-parallel to black laminae. Elsewhere, the purple laminae form an anastomosing hairline veinlet system into the black portions.
- EF-38 Manganiferous dolostone - dolomite rhombs and angular grains uniformly 1 - $1/2$ to 2 mm across. Rhombs are pinkish gray (5YR8/1), very light gray (N8) or light brownish gray (5YR6/1).

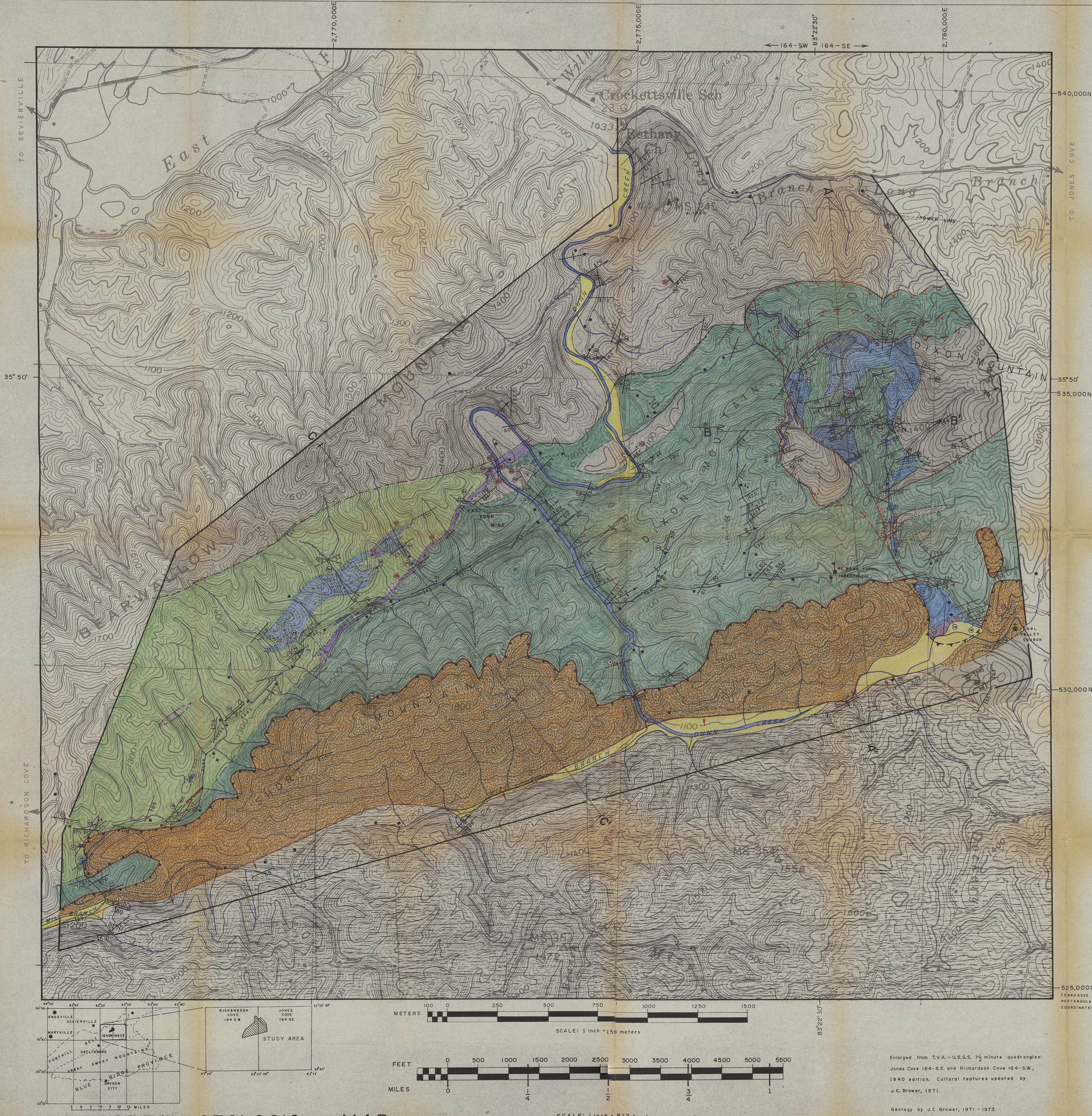
- EF-38
(Cont'd) Specimen is 75% dolomite grains, 25% interstitial medium gray (N5) manganese oxides.
- EF-39 Argillite - medium gray (N5) overall, slightly calcareous or dolomitic as indicated by very weak rxn w/HCL. A few laminae can be seen, 1 mm thick. Grains are $<1/10$ mm. Very well indurated.
- EF-40 Manganiferous dolostone - dolomite rhombs and angular grains 1 to 1-1/2 mm, very light gray (N8) to pinkish gray (5YR8/1). Clusters to 10 mm of anhedral pyrite are common. Specimen is 50% black, very hard manganese ore w/discrete dolomite grains or aggregations of grains throughout constituting ~45% of the mass, py. ~5%.
- EF-41 Sinter, vesicular manganese ore - vesicles are coated with shiny black semi-colloform manganese, w/buds $<1/10$ mm. Partly limonitic (~25%).
- EF-42 Dolostone - medium light gray (N6) overall, grain size $<1/10$ mm. Specimen is cut by numerous subparallel 1 to 2 mm milky qtz. veins. Pyrite as anhedral flecks is common, ranging to $1/10$ mm.
- EF-43 Manganiferous dolostone - speckled dark gray (N2) and very light gray (N8) overall due to light gray 1 mm dolomite grains and aggregates of grains in manganese oxide or dark dolomite. Grains average $<1/10$ mm. Disseminated py. anhedral grains $<1/10$ mm are common.
- EF-44 Manganiferous dolostone - containing abundant pyrite. Very dense and heavy. Dark overall w/white discrete dolomite rhombs and two blackish red (SR2/2) chert bands. Dolomite rhombs range from $<1/4$ mm across, to 4 x 2 mm. Py. cubes are disseminated throughout and range from $1/4$ to $3/4$ mm. Two $1/4$ mm pyrite veinlets cut the black dolomite and chert. Composition overall is 75% MnO, 25% dolomite, chert and pyrite.
- EF-45 Manganiferous dolostone - grayish black (N2) overall. Dolomite grains $<1/4$ mm. Pyrite is abundant, occurs as euhedra to $1/2$ mm, and anhedral masses to 2 mm. Py. cubes occupy 50% of area of some scattered 5 mm zones.
- EF-46 Manganiferous dolostone - massive, grayish black (N2) overall and has a slight magnetic susceptibility, sufficient to attract a small suspended hand magnet. Granularity of specimen is obscured by weathering and alteration.

- EF-47 Siltstone - dark yellowish orange (10YR6/6) overall, deeply weathered, extensive alteration to clay minerals. Laminae range from 1 to 3 mm, are slightly distorted in color. One relatively thick lamination exhibits grains to 1/2 mm. Manganese oxide selvages occur along some laminae, rarely attaining 2 mm in thickness.
- EF-48 Micrograywacke - medium light gray (N6) on fresh surface, moderate yellowish brown (10YR5/4) on weathered. Deeply weathered. Grain size $<1/4$ mm. Laminae range from 1 to 4mm+, are slightly distorted. Specimen represents a bed 40 mm thick.

VITA

John Charles Brower was born in Portland, Oregon, on February 12, 1937. He attended elementary schools in that city and graduated from Benson Polytechnic School in 1955. His undergraduate work began at Portland State College and was completed at The Tulane University in New Orleans, where, in August, 1968, he received a Bachelor of Science degree in Geology. He began graduate studies at the University of South Carolina in September, 1968, and transferred in January, 1969 to the Graduate School at the University of Tennessee.

During his graduate studies at the University of Tennessee he was a graduate assistant whose duties included teaching laboratory sections of introductory Geology, Structural Geology, and Engineering Geology. He also served as Vice President of the Graduate Student Association, and worked during summers as a field geologist. In April, 1971, he began study toward a Ph.D. degree in Mineral Economics at The Pennsylvania State University while completing the Master's degree in absentia. He received the Master of Science degree with a major in Geology from the University of Tennessee in June, 1973.



TRUE NORTH GRID NORTH

LEGEND

QUATERNARY ALLUVIUM	
FINE TO MEDIUM GRAINED SANDSTONE, CALCAREOUS AT BASE	
SLATY SILTSTONE	
DOLOSTONE AND CARBONATE CONGLOMERATE	
SILTSTONE	
COARSE TO MEDIUM GRAINED SANDSTONE	
SHIELDS? CONGLOMERATE	
PIGEON SILTSTONE	

GEOLOGICAL CONTACT	
INFERRED CONTACT	
FOOTPATH	
STRIKE AND DIP	
OVERTURNED BEDS	
CLEAVAGE	
JOINT	
VERTICAL JOINT	
CONTORTED BEDS - ARROW INDICATES STRIKE	
SAMPLE LOCATION OF "JB" SERIES, PINK INDICATES XRF ANALYSIS.	
BORROW PIT	
MINE	
PROSPECT	
THRUST FAULT - TEETH ON THRUST PLATE	
INFERRED	
FAULT - HIGH ANGLE	

STRUCTURE SECTIONS ARE INDICATED BY LINES A-A', B-B', C-C'

PLATE 1. AREAL GEOLOGIC MAP

Enlarged from T.V.A. - U.S.G.S. 7 1/2 minute quadrangles: Jones Cove 164-SE and Richardson Cove 164-SW, 1940 edition. Cultural features updated by J.C. Brower, 1971.

Geology by J.C. Brower, 1971 - 1973.

HYPOTHETICAL STRUCTURE SECTIONS, ILLUSTRATING FACIES CHANGE

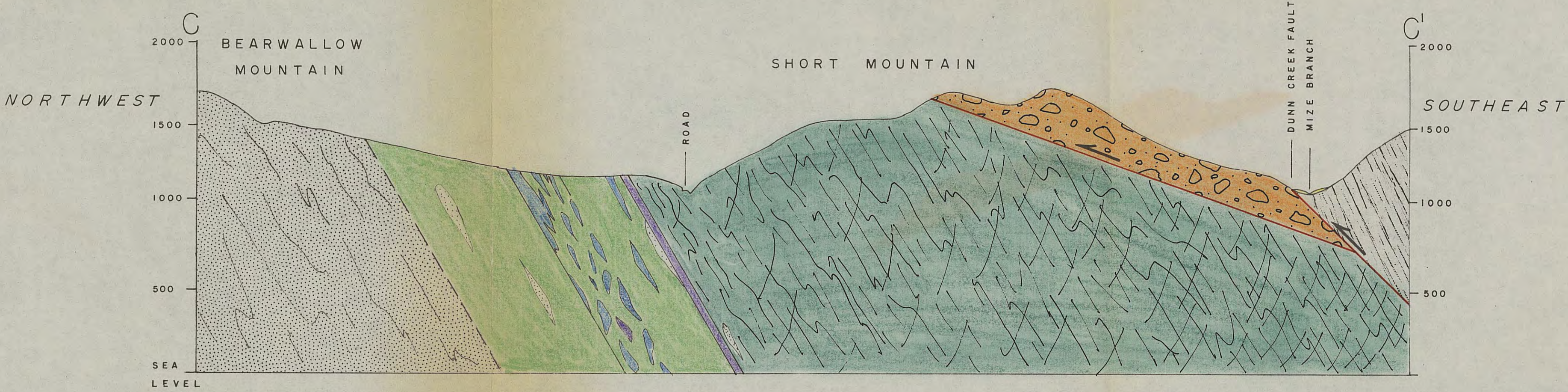
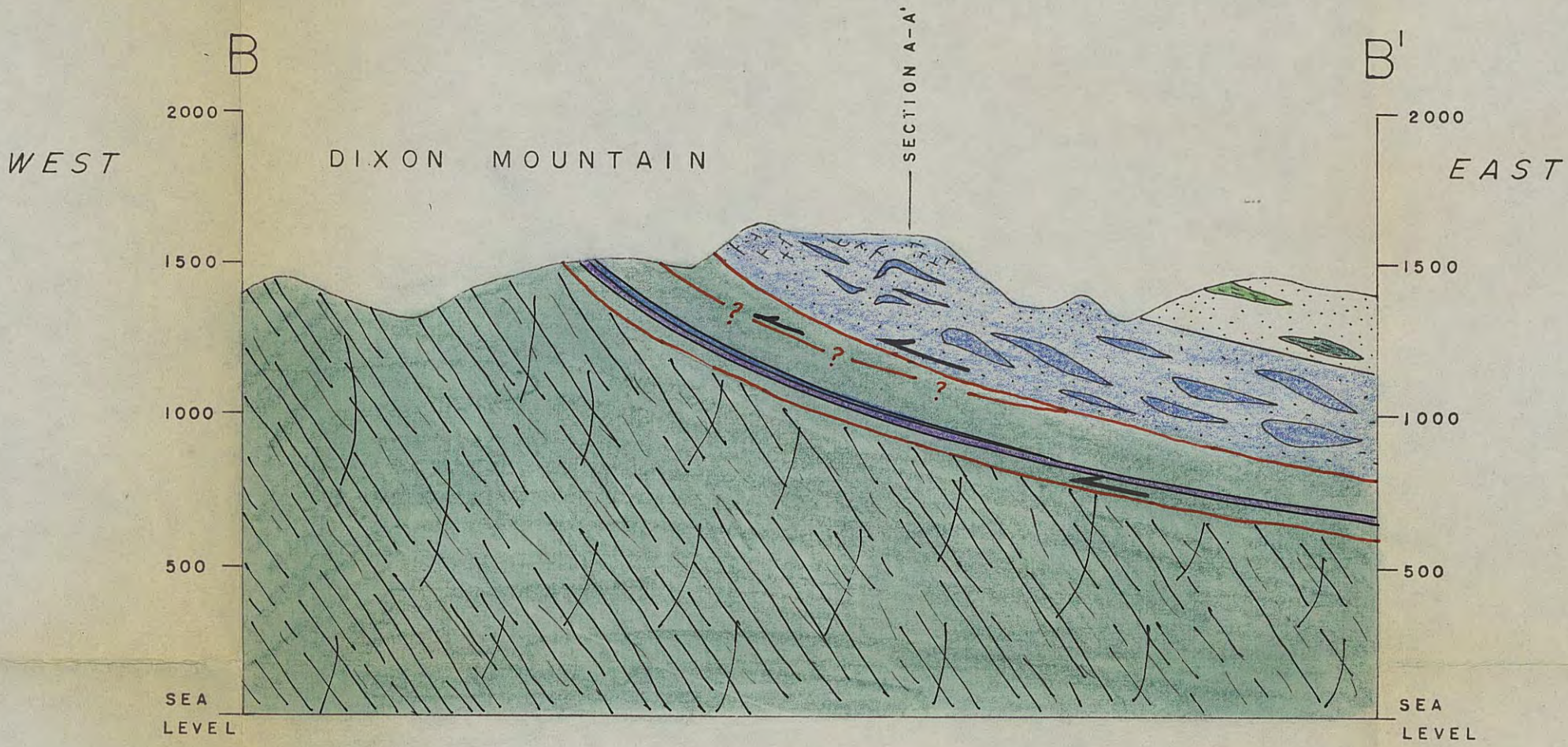
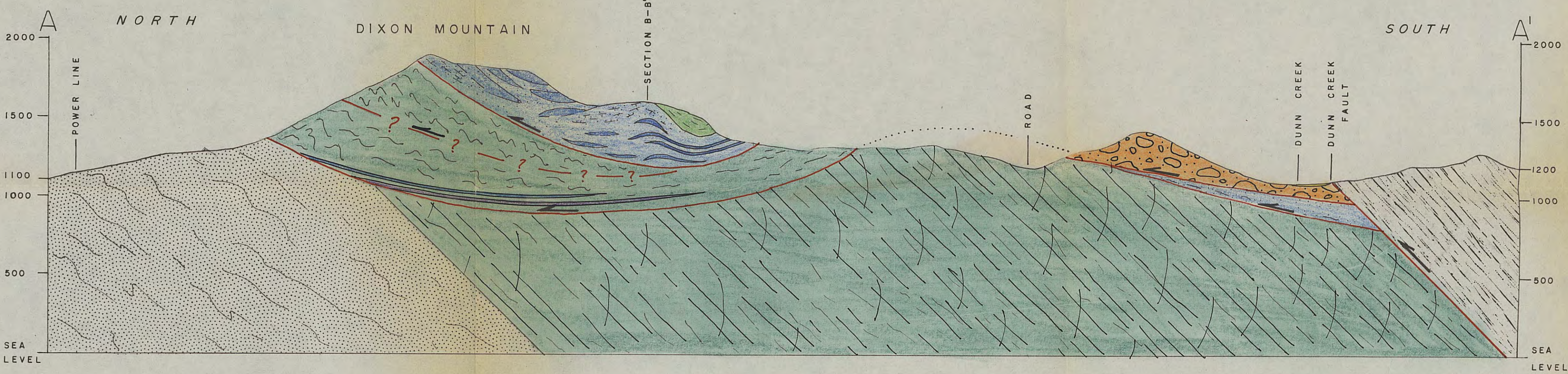
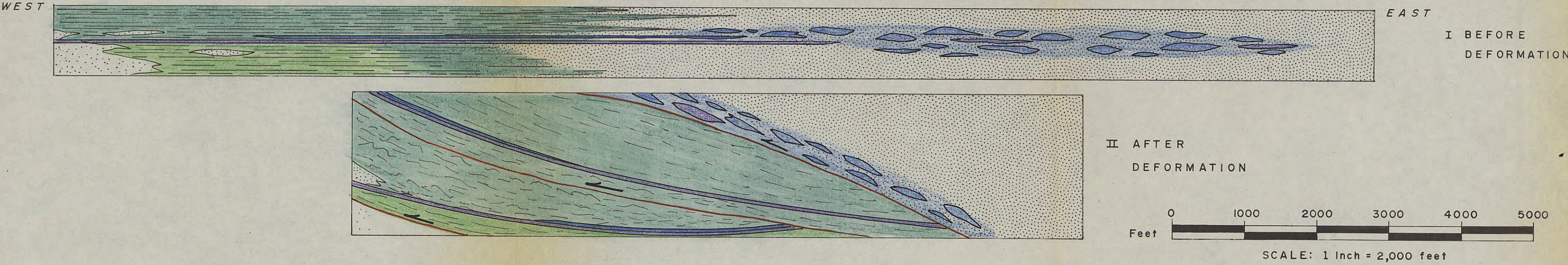
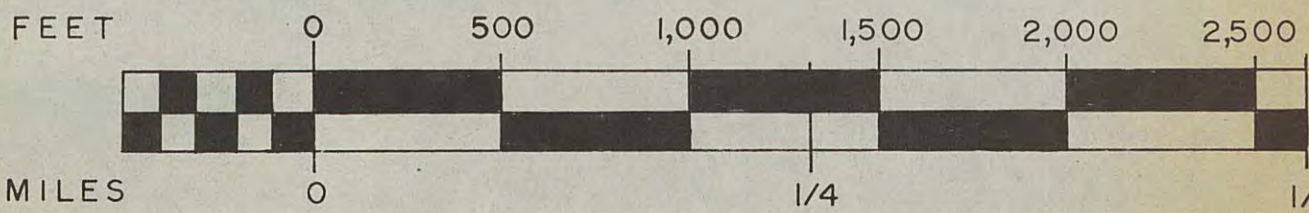
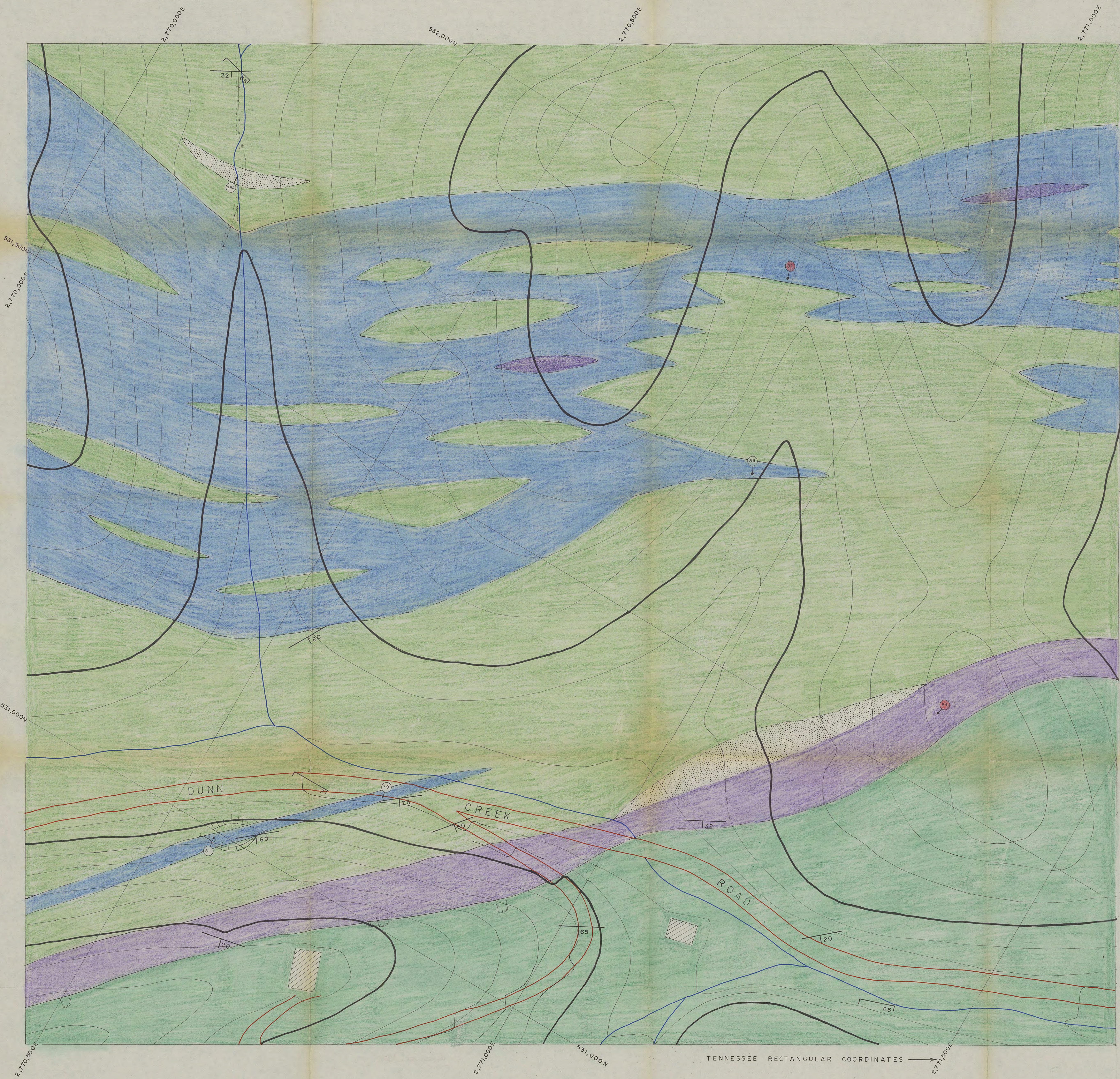


PLATE 2. STRUCTURE SECTIONS





LEGEND

TRUE NORTH
GRID NORTH
1/3°

SILTSTONE

SLATY SILTSTONE

SANDSTONE

DOLOSTONE

LIMESTONE AND CARBONATE CONGLOMERATE

CONTACT

APPROXIMATE CONTACT

STRIKE AND DIP OF BEDS

OVERTURNED BEDS

CLEAVAGE

JOINT

Base map and geology by J.C. Brower, 1971-1973.
Topography is enlarged from portions of Plate 1.

ROAD

FOOTPATH

OPEN CUT

OPEN CUT WITH OVERHANG

DUMP, BENCH OR MOUND

WIRE FENCE

BUILDING

SAMPLE LOCATIONS:

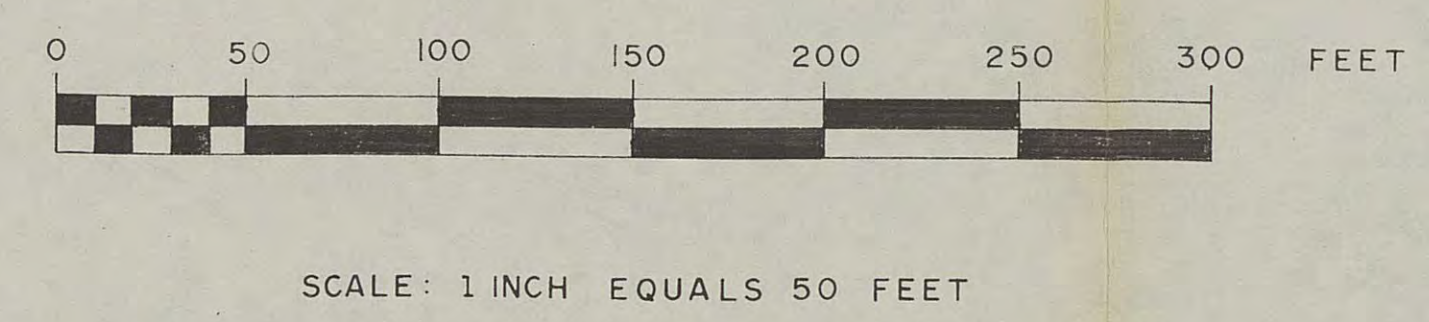
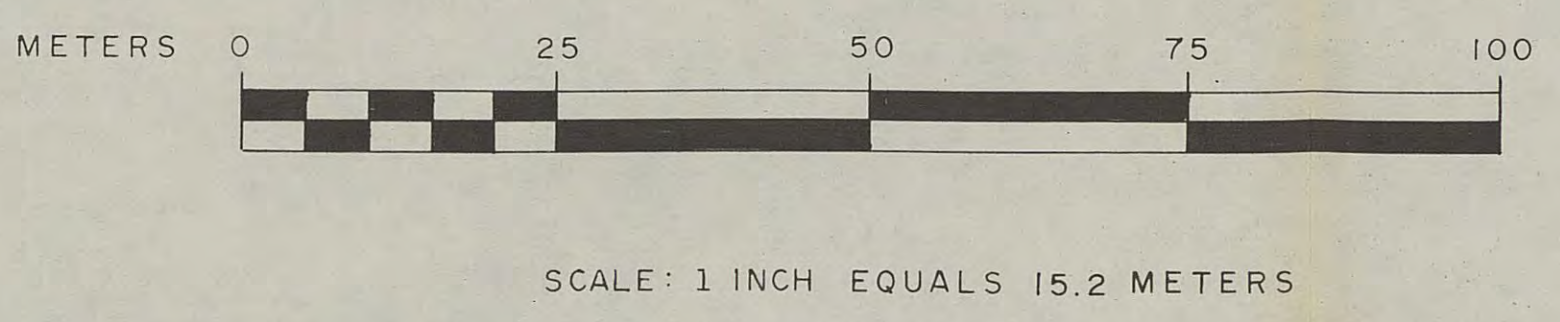
"JB" RECONNAISSANCE SERIES

EAST FORK SERIES

PINK INDICATES

XRF ANALYSIS

PLATE 3, EAST FORK
WESTERN ZONE



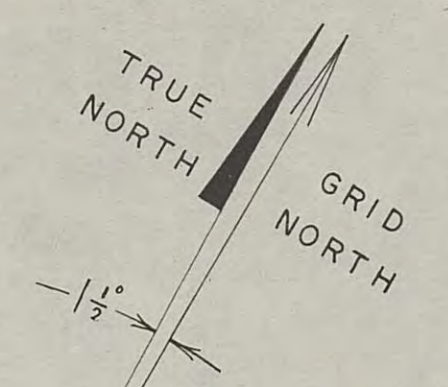


TRUE NORTH
GRID NORTH
-1 1/2°

LEGEND

- SILTSTONE
- SLATY SILTSTONE
- SANDSTONE
- DOLOSTONE
- LIMESTONE AND CARBONATE CONGLOMERATE
- CONTACT
- APPROXIMATE CONTACT
- STRIKE AND DIP OF BEDS
- OVERTURNED BEDS
- CLEAVAGE
- JOINT
- ROAD
- FOOTPATH
- OPEN CUT
- OPEN CUT WITH OVERHANG
- DUMP, BENCH OR MOUND
- WIRE FENCE
- BUILDING
- SAMPLE LOCATIONS:
- "JB" RECONNAISSANCE SERIES
- EAST FORK SERIES
- PINK INDICATES XRF ANALYSIS

PLATE 4, EAST FORK
CENTRAL ZONE



LEGEND

- SILTSTONE
- SLATY SILTSTONE
- SANDSTONE
- DOLOSTONE
- LIMESTONE AND CARBONATE CONGLOMERATE
- CONTACT
- APPROXIMATE CONTACT
- STRIKE AND DIP OF BEDS
- OVERTURNED BEDS
- CLEAVAGE
- JOINT

Base map and geology by J.C. Brower, 1971-1973.
Topography is enlarged from portions of Plate 1.

- ROAD
- FOOTPATH
- OPEN CUT
- OPEN CUT WITH OVERHANG
- DUMP, BENCH OR MOUND
- WIRE FENCE
- BUILDING

SAMPLE LOCATIONS:
"JB" RECONNAISSANCE SERIES
EAST FORK SERIES
PINK INDICATES
XRF ANALYSIS

PLATE 5, EAST FORK EASTERN ZONE

